VAN NOSTRAND'S

ECLECTIC

ENGINEERING MAGAZINE.

NO. CXIII.—MAY, 1878.—VOL. XVIII.

A NEW GENERAL METHOD IN GRAPHICAL STATICS.

By HENRY T. EDDY, C. E., Ph. D., University of Cincinnati.

Written for VAN NOSTRAND'S MAGAZINE.

V.

UNIFORMLY VARYING STRESS IN GENERAL.

The methods employed in Figs. 13 and 14 are applicable also to any uniformly varying stress, for a stress which uniformly increases from any neutral axis x through the center of gravity of the cross section can be changed into a stress which uniformly increases from same parallel axis x' at a distance y_0 from x by simply combining with the former a stress uniformly distributed over the cross-section and of such intensity as to make the resultant intensity zero along x'.

In the construction given in Figs. 13 and 14 it is only necessary to use the proposed line x' at a distance y_0 from o, instead of the tangent to the extreme fiber at a distance y_1 or y_2 from o, when we wish to determine the weight or volume of the resultant stress solid, its moment about o, and its center of gravity or application.

Since the locus of the center of application of the resultant stress is the antipole of x' with respect to the ellipse of inertia, it is evident that when the proposed axis x' lies partly within the cross section the center of application of the resultant stress is without the kernel, and that when x' is entirely without the cross section its center of application is within the kernel.

It is frequently more convenient to determine the center of application from the kernel itself than from the ellipse of inertia. This can be readily found from the equation which we are now to state

$$Ar_0y_0 = Ar_1y_1 = I,$$

in which equation Ay_0 and Ay_1 are the volumes of the stress solids which if uniformly distributed and compounded with the stress whose neutral axis is x, will cause the resultant stresses to vanish at distances y_0 and y_1, respectively; while r_0 and r_1 are the distances from o of the respective centers of application of these stresses.

The truth of the equation is evident from the fact that the moment about o of any stress solid uniformly distributed is zero, hence the composition of such a stress with that previously acting will leave its moment unchanged.

From the equation just stated we have

$$y_0 : y_1 :: r_1 : r_0,$$

from which r_0 can be found by an elementary construction, since y_0, y_1 and r_1 are known quantities. When it is de-

sired to express these results in terms of the intensities of the actual stresses,

let $p_0 = ny_0$ be the mean stress;
and let $p_1' = n\,(y_0 + y_1)$ be the greatest,
and let $p_2' = n\,(y_0 - y_2)$ be the least
intensity at the extreme fiber:

then $ny_1 = p_1' - ny_0 = p_1' - p_0$
or $ny_2 = ny_0 - p_2' = p_0 - p_2'$
$\therefore$ $p_0 : p_1' - p_0 :: r_1 : r_0$
or $p_0 : p_0 - p_2' :: r_2 : r_0$

in which r_1 and r_2 are the two radii of the kernel.

DISTRIBUTION OF SHEARING STRESS.

It is well known that the equation $dM = Tdz$, expresses the relation of the total shearing stress T sustained at any cross section of a girder to the variation dM of the bending moment M at a parallel cross-section situated at the small distance dz from the first mentioned cross section.

We have already treated the normal components of the stress caused by the bending moment M: we shall now treat the tangential component or shear which accompanies any variation of the bending moment.

We shall assume as already proved the following equation* which expresses the intensity q of the shearing stress at any point of the cross section:

$$Iqx = TV$$

in which x is the width of the girder measured parallel to the neutral axis at any distance y from the neutral axis, and q is the intensity of the shearing stress at the same distance, I is the moment of inertia of the cross section about the neutral axis, T is the total shear at this cross section, and V is the volume of that part of one of the stress solids used in finding the moment of inertia which is situated at a greater distance than y from the neutral axis, *i.e.* in Fig. 13 if we were finding the value of q at b_2, with respect to om_2 as the neutral axis, then V would signify the stress solid whose profile is $d_1 d_2\, b_2 b_1$. It, however, makes no difference whether we define V as the stress solid situated at the left or at the right of b_2; for, since the total stress solid, positive and negative, is zero, that on either side of any assumed plane is the same.

The first step in our process is to find the intensity of the shear at the neutral axis, which we denote by q_0; and if we also call x_0 the width here and V_0 the volume of either of the two equal stress solids between this axis and the extreme fiber, we have

$$Iq_0x_0 = T\,V_0, \text{ but } I = V_0 d$$

when d is the distance between the centers of application of the equal stress solids, *i.e.*, d is the arm of the couple of the resultant stresses. Also $T = A\bar{q}$ when A is the total area of the cross section and $\bar{q}$ is the mean intensity of the shearing stress. Hence at the neutral axis we have the equation

$$q_0x_0d = A\bar{q} = T$$

Now the length of the arm d is found in Fig. 13 by prolonging the middle side (*i.e.* the side through n_2) of the second equilibrium polygon until it intersects the first side and the last. These intersections will give the position of the centers of gravity of the stress solids on either side of o.

In Fig. 14 the same points are found by drawing rays from v parallel respectively to $z_1 f_0$ and $f_1 f_0$ until they intersect aa.

In Fig. 15 the points f_1 and f_2 are found by either of these methods and $f_1 f_2 = d$ is the required distance.

Now in Fig. 15 let the segments uu of the summation polygon be obtained just as in Fig. 14, and parallel to uu draw a line through s representing the width of the cross section x_0 on the same scale as before used in constructing the summation polygon. Also make $su_1 \parallel cf_2$ and $su \parallel cf_1$, c being the common point in the rays of the pencil of the summation polygon for finding the area.

Then uu_1 represents the product $x_0 d$ on same scale that u_1u_1 represents A. Now draw from any point i rays to u_1, u and u_2, and also a parallel to iu_1 at a distance $\bar{q}$ and intersecting iu at some point t_0 such that $tt_0 = \bar{q}$ to such a scale as may be convenient. The mean intensity $\bar{q}$ is supposed to be a known quanti-

* See Rankine's Applied Mechanics. Eighth Edition, Art. 309, p. 338.

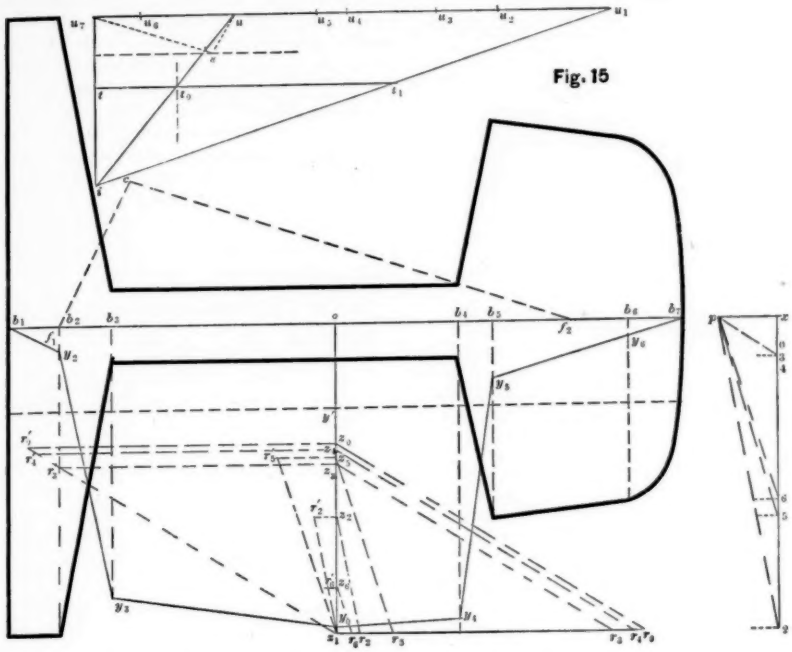


Fig. 15

ty, and $tt_0 \parallel uu$. Then from the proposed equation we have the proportion

$$x_0 d : A : : \bar{q} : q_0$$

or $$uu_7 : u_1u_7 : : tt_0 : tt_1$$

Hence tt_1 represents the intensity of the shearing stress at the neutral axis on the same scale that tt_0 represents the mean intensity.

This first step of our process has determined the intensity of the stress at the neutral axis relatively to the mean stress; the second step will determine the intensity of the stress at any other point relatively to the stress at the neutral axis. When this last point is all that is desired the first step may be omitted.

The equation $Ixq = TV$ may be written $xq = cV$, in which $c = T \div V$ is a constant. At the neutral axis this equation is

$$x_0 q_0 = cV_0 \text{ or } V_0 : q_0 : : x_0 : c$$

In Fig. 15 lay off the segments of the line zz just as in Fig. 14; then z_1z_0 represents the weight or volume V_0; also make $x0$, $x2$, $x3$, etc., proportional to width of the girder at o, b_2, b_3, etc., and lay off $z_1r_0 = z_0r_0' = tt_1$.

Draw $p0 \parallel r_0z_0$, then by similar triangles

$$z_1z_0 : z_1r_0 : : x0 : xp$$

or $$V_0 : q_0 : : x_0 : c$$

$\therefore$ px represents the constant c.

Now the several segments z_1z_2, z_1z_3, z_1z_4, etc., represent respectively the values of V_2, V_3, V_4, or the stress solids between one extreme fiber and b_2, b_3, b_4, etc.; it is of no consequence which extreme fiber is taken as the stress solid is the same in either case.

Now using p as a pole draw rays to 2 3 4 5 etc., and make $z_2r_2 \parallel p2$, $z_3r_3 \parallel p3$, etc., then by similar triangles

$$z_1z_2 : z_1r_2 : : x2 : c, \text{ or } x_2q_2 = cV_2$$

and $$z_1z_3 : z_1r_3 : : x3 : c, \text{ or } x_3q_3 = cV_3$$

etc., etc., and z_1r_2, z_1r_3, etc., represent the intensity of the shearing stresses at b_2, b_3, etc. These can be constructed equally well by drawing rays from z_1 parallel to the rays at p, from which we obtain

$$z_2r_2'=z_1r_2,\ z_3r_3'=z_1r_3,\ \text{etc.}$$

Now lay off $b_2y_2=z_1r_2$, $b_3y_3=z_1r_3$, etc., then the ordinates by of the polygon yy represent the intensity of the shearing stress on the same scale that $tt_1=z_1r_0$ represents the intensity q_0 at the neutral axis, and on the same scale that $tt_0=oy'$ represents the mean intensity $\overline{q}$. The lines joining y_2, y_3, etc., should be slightly curved, but when they are straight the representation is quite exact.

RELATIVE STRESSES.

It is proposed here to develop a new construction which will exhibit the relative magnitude of the normal components of the stresses produced by a given system of loading in the various cross-sections of a girder having a variable cross section. The value of such a construction is evident, as it shows graphically the weakest section, and investigates the fitness of the assumed disposition of the material for sustaining the given system of loading.

The constructions heretofore given for the kernel and moments of resistance at any given cross section admit of the immediate comparison of the normal components of the stresses produced in that single cross section when different neutral axes are assumed, but by this proposed construction, a comparison is effected between these stresses at any different cross sections of the same girder or truss.

In the equation previously used

$$M=SI\div y=SAk^2\div y=SAr$$

in which M is the moment of flexure which produces the stress S in the extreme fiber of a cross section whose area is A and whose radius of resistance is r, we see, since the specific moment of resistance $m=Ar$ is the product of two factors, that the same product can result from other and very different factors.

For example, let $m=A_0r'$ in which A_0 is the area of some cross section which is assumed as the standard of comparison, and $r'=Ar\div A_0=ar$, when $a=A\div A_0$. Then is A_0r' the specific moment of resistance of a cross section of an assumed area A_0 which has a different disposition of material from that whose specific moment of resistance is Ar, but the cross sections A and A_0 are equivalent to each other in this sense, that they have the same specific resistance, and consequently the same bending moment will produce equal stresses in the extreme fiber in each.

The two cross sections do not have the same moment of inertia, and so the deflections of the girder would be changed by substituting one cross section for the other. We shall then speak of them as equivalent only in the former sense, and on the basis of this definition, state the result at which we have arrived thus: Equivalent cross sections under the action of the same bending moment, have the same stresses at the extreme fiber (though they are not equally stiff); hence in comparing stresses equivalent cross sections may be substituted for each other (but they may not be so substituted in comparing deflections).

It is proposed to utilize this result by substituting for any girder or truss having a variable cross section A or a variable specific moment of resistance whose magnitude is expressed by the variable quantity Ar, a different one having a cross section everywhere of constant area A_0, but of such disposition of material that its specific moment of resistance is $A_0r'=Ar$ at corresponding cross sections.

The proposed substitution is especially easy in case of a truss, for in it the value of r varies almost exactly as its depth, as may be seen when we compute the value of

$$m=Ak^2\div y=Ar$$

in this case.

Since the material which resists bending is situated in the chords alone and is all approximately at the same distance from the neutral axis we have $k=y=r=\frac{1}{2}h$ very nearly when h is the distance between the chords, $\therefore m=\frac{1}{2}Ah$ nearly. Even when the two chords are of unequal cross section and the neutral axis not midway between them the same result holds when the ratio of the two cross sections is constant.

In Fig. 16 let xx be the axis of a girder sustaining at the points x_1, x_2, etc., the weights c_1c_2, c_2c_3, etc. Lay off the ordinates xy at each of the points at which weights are applied, so that $xy=Ar$ on some assumed scale; then since

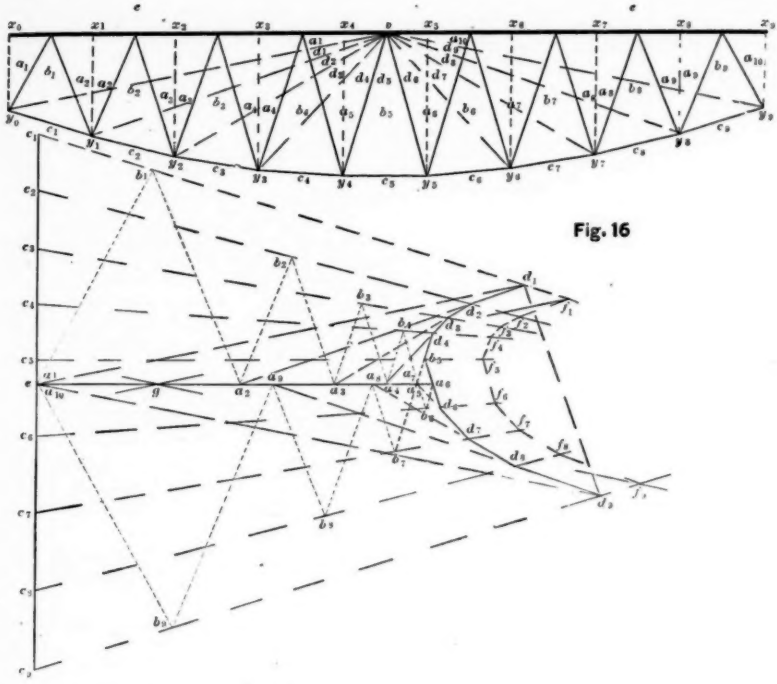


Fig. 16

$A_0 r' = Ar = xy$, xy varies as r', the radius of resistance of a girder having at every point a cross section A_0 so disposed as to be equivalent to that of the given girder xx.

Assume some form of framing connecting the points xy as shown in the Fig., and suppose the weights applied at the points yy of the lower chord, the points of support being at y_0 and y_9. Then by a method like that employed in Fig. 3, we obtain the total stresses ea_2, ea_3, ea_4, etc., in the segments of the upper chord which are opposite to y_1, y_2, y_3, etc. Now these total stresses are resisted by a cross section of constant area A_0, consequently they have the same ratio to one another as the intensities per square unit; or further, they represent, as we have just shown, the relative intensities of the stresses on the extreme fiber of the given girder.

It is well known from mechanical considerations, that the stress in the several segments of the upper chord is dependent upon the loading and upon the position of y_1, y_2, etc., and is not dependent upon the position of the joints in the upper chord. Of this fact we offer the following geometrical proof derived from the known relations between the frame and force polygons.

We know, if any joint of the upper chord, such as ea_2b_1 for example, be removed to a new position, such as v, that so long as the weights c_1c_2, c_2c_3, etc., are unchanged, that the vertex b_1 of the triangle ea_2b_1 in the force polygon must be found on the force line $c_1f_1 \parallel y_0y_1$. We shall show that while the side ea_2 is unchanged, the locus of b_1 is the force line c_1f_1; hence conversely, so long as c_1f_1 is the locus of b_1, ea_2 is unchanged, since there can be but one such triangle.

In Fig. 17 let the two triangles abe, hnk, have the sides meeting at b and n mutually parallel. Let the bases ae and hk be invariable but let the vertex b be removed to any point d such that $bd \parallel hk$, then will the vertex n be removed to a point m such that $mn \parallel ae$.

For, prolong ad and eb, and draw

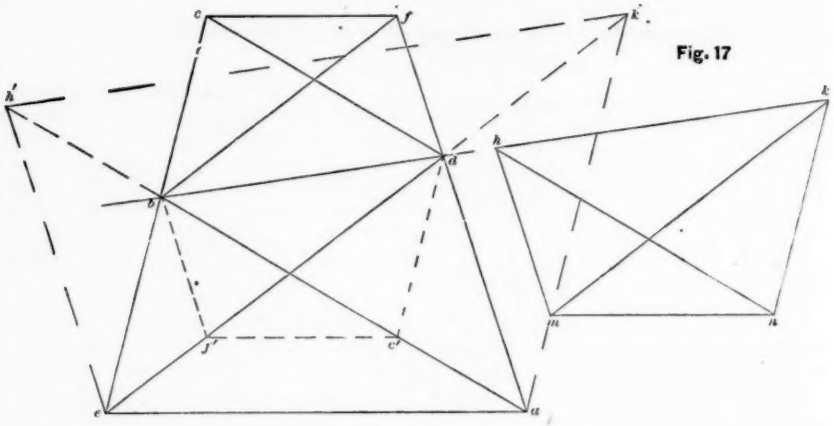


Fig. 17

$bf \parallel ed$ and $dc \parallel ab$, then is $abfcdea$ a hexagon inscribed in the conic section consisting of the two lines af and ec, hence by Pascal's Theorem, the opposite diagonals ea and cf intersect on the same line as the remaining pairs of opposite diagonals, $ab \parallel dc$ and $ed \parallel bf$. But this line is at infinity, hence $cf \parallel ae$. Also $c'f' \parallel cf$, from elementary considerations; and $c'f' \parallel mn$ from similarity of figures, hence $mn \parallel ae$. There are two cases, according as mn is above or below hk, but we have proved them both.

Now in Fig. 16 let all the joints in the upper chord be removed to v, then the segments ea_2, a_2a_3, etc., are unchanged, hence ea_3, ea_4, etc. are unchanged, and the assumed framing reduces to the frame pencil whose vertex is v. The corresponding force polygon is the equilibrating polygon dd.

Hence the frame pencil can be used as the assumed framing just as well as any other form of framing, and it is unnecessary to use any construction except that of the frame pencil and equilibrating polygon for finding the relative stresses ea_2, ea_3, etc.

STRESSES IN A HORIZONTAL CHORD.

If Fig. 16 be regarded as representing an actual bridge truss, whose chords are not of uniform cross section; it is seen that the total stresses on the horizontal chord are given by the segments ea_2, ea_3, etc., which are found from the equilibrating polygon alone without regard to the kind of bracing in the truss, which it is unnecessary to consider; and this method can be used to take the place of that given in connection with Fig. 3 for finding the maximum stresses on the chords.

The equilibrating polygon ff was constructed to determine the reactions of the piers by finding the point e. The outer sides of the polygon ff intersect at g which determines e as explained in Fig. 7 in a manner different from that given in Fig. 3.

This construction sheds new light upon the significance of the frame pencil and equilibrating polygon. The frame pencil is the limiting case of a truss when the joints along one chord are removed to a single point, so that each ray may be regarded as compounded of a tension member and a compression member, having the same direction, *e.g.*, the tension member of which y_1v is compounded has the stress d_1a_2, and the compression member the stress d_2a_2, but if the two be combined, the resultant tension is d_1d_2.

In case yy is the equilibrium curve due to the applied weights, and v falls upon the closing line, the force lines cd meet at the pole and the lines ed_1, ed_2, coincide with aa, so that the polygon dd is at the pole and infinitely small, and the stress in every segment of the upper chord is equal to the pole distance de.

SUPPLEMENTARY NOTE TO THE "NEW CONSTRUCTIONS IN GRAPHICAL STATICS."*

The truth of Proposition IV is, perhaps, not sufficiently established in the demonstration heretofore given. As it is a fundamental proposition in the graphical treatment of arches, and as it is desirable that no doubt exist as to its validity, we now offer a second proof of it, which, it is thought, avoids the difficulties of the former demonstration.

Prop. IV. If in any arch that equilibrium polygon (due to the weights) be constructed which has the same horizontal thrust as the arch actually exerts; and if its closing line be drawn from consideration of the conditions imposed by the supports, etc.; and if, futhermore, the curve of the arch itself be regarded as another equilibrium polygon due to some system of loading not given, and its closing line be also found from the same considerations respecting supports, etc.; then when these two polygons are so placed that their closing lines coincide, and their areas partially cover each other, the ordinates intercepted between these two polygons are proportional to the real bending moments acting in the arch.

The bending moments at every point of an arch are due to the applied forces and to the shape of the arch itself.

The applied forces are these: the vertical forces, which comprise the loading and the vertical reactions of the piers; the horizontal thrust; and the bending moments at the piers, caused by the constraint at these points of support. The loading may cause all the other applied forces or it may not: in any case the bending moments are unaffected by the dependence or want of dependence of the thrust, etc., upon the loading.

Now, so far as the loading and the moments due to the constraint at the piers are concerned, they cause the same bending moments at any point of the arch as they would when applied to a straight girder of the same span, for neither are the forces nor their arms different in the two cases. But the horizontal thrust, which is the same at every point of the arch, causes a bending moment proportional to its arm, which is the distance of its line of application from the curve of the arch. This line of application is known to be the closing line; hence the ordinates which represent the bending moments due to the horizontal thrust, are included between the curve of the arch and a closing line drawn in such a manner as to fulfill the conditions imposed by the joints or kind of support at the piers.

But the same conditions fix the closing line of that equilibrium polygon which represents the bending moments due to the loading and to the constraint at the piers. Hence the resultant bending moment is found by taking the difference of the ordinates at each point, or by laying them off from one and the same closing line exactly as described in the statement of our proposition.

* See Van Nostrand's Engineering Magazine, Vol. XVI.

SPRINGS.

By ARTHUR DE BONNEVILLE, Jr., Class of 1878, Stevens Institute of Technology, Hoboken, N. J.

Contributed to Van Nostrand's Magazine.

I.

In this essay on Springs, I treat the subject by first giving a view of the materials, forms, sizes, uses and manufacture of springs, in general, and secondly, by taking up the Helical Spring in particular and in detail, and especially in its connection with India rubber: Rubber Springs are also considered by themselves.

The second part describes the means employed, the *modus operandi*, and the results of the tests of helical springs.

A spring may be defined to be a *medium*, which, by reason of its elasticity, will yield, when actuated by a force, without detriment to the material of which it is manufactured or to the form in which it is employed.

Various devices are used to obtain such a medium, which are all dependent upon the elasticity of the substance used, or upon that and the special form which it is made to assume.

The form should be so chosen as to give the required flexibility, with an easy, uniform, sensitive and elastic action, without abrasion. It should be compact in form, economizing space; of the least

weight allowable, economising first cost and locomotive power, if used in that connection; and should be so placed in connection with mechanisms as to be accessible at all times for examination, repairs, or replacement.

THE MATERIAL should be of a nature the least possible affected by the ordinary changes of temperature, and the best capable of enduring the wear and tear, to which it will naturally be subjected. It should moreover be, in the form of its manufacture and its fittings, of an appearance the least clumsy and uncouth, compatible with the nature of its uses.

MATERIAL.

The spring which resists by direct compression or extension, and is of the form of a solid block, generally consists of a material which admits of an appreciable distortion, before resisting considerably.

By experiment it has been found that India rubber, used in this shape will act very well for compression; but when attempted to be used as a tension organ, it soon loses its elasticity: for the other forms, metals, brass, steel, wood, compressed air, combined rubber and steel are used. The ancients made springs of bronze, containing three or four per cent. of tin (carriage springs were unknown among them).

In this country, for helical springs, cast steel and brass are used; brass is found advantageous for the reason that it does not necessitate any subsequent tempering, the brass being hardened by being sufficiently drawn without annealing; for flat brass springs, cold rolled sheet brass, which appears smooth and is rigid and glossy, is used.

FORMS.

Springs are familiar in many forms; we may have a solid piece which resists by direct compression or tension; a plate, plain or curved, which resists by flexion; a helix which resists by torsion; and gases have been used as elastic mediums. As examples, we have the rubber spring, the elliptic spring, the helical spring and the pneumatic spring.

Under each of the above-named heads there is a variety of subsidiary shapes and combinations, from the plate to the sphere, that present themselves.

Rubber springs are generally cylindrical or barrel shaped; the elliptic and helical as the names imply, have respectively the shape of an ellipse and helix. The helical spring is generally made of a material cylindrical in cross section, though that is not always the case.

The different kinds of pneumatic springs that have been introduced, have consisted, mainly, of metallic cylinders with pistons.

THE SIZES of springs vary, from the delicate hair spring of the watch, in which the increase or decrease of one one hundredth part of an inch in the length makes a great change in the action of the spring, to springs that are large enough to be used to propel street cars.

Of the smallest kind of springs used, that is to say, the hair springs of time pieces, there is a variety: we have the flat spiral, which was the form up to the time of Arnold, who introduced the helical spring. The Breguet spring, the body of which is flat, with the outer coil bent upwards with a gentle sweep, and again bent so as to bring the length parallel to the plane of the spring; from there it is curved toward the center.

Houriet, a Swiss watch-maker, invented a balance spring, spherical in form.

In Sheffield they have means of making springs from fifty to sixty feet in length, capable when coiled of exerting a pressure of 800 to 900 pounds.

In France steel driving bands with great elasticity are made one hundred yards in length.

USES.

Springs are used to resist shock, to make dynamometrical observations, to transmit force, to store energy, to regulate motion, &c.

The rubber spring which is used to resist shock, is generally used on railways, either by itself or in connection with metallic springs, the main point in its application being to prevent abrasion, which would soon destroy the material.

With the many applications of elliptic springs to wagons, carts, carriages, &c., every one is familiar.

The helical spring serves us best for

making dynamometrical observations. All the three kinds just mentioned are extensively used to resist shock. To store energy we mostly use the coiled spring, as the main spring of the watch.

As an example of the use of a spring for regulating motion, we have the hair spring of the time piece.

An important application of springs is made in supplying the force to close incomplete pairs of elements, as in case of spring packed pistons, spring pawls for ratchet wheels, &c.

MANUFACTURE.

The general process of making springs is to give to the material its proper form, and then subject it to a temperature that will give it the desired elasticity.

The spring of the form of a solid block, when made of rubber, is manufactured by winding a sheet of rubber properly manipulated on an iron mandrel and then vulcanizing it.

The elliptic spring is made of a series of plates, held together by bands and worked by the ordinary processes of forging and tempering. There is generally a continuous or hoop plate upon which the reinforce or short leaves are distributed, inside at the ends and outside at the center, thus distributing the action over the whole length of the hoop.

The helical spring is made by coiling the wire or rod of which it is to be made on a mandrel, by means of a proper guide curve and then tempering.

The pneumatic spring is made by the processes of an ordinary machine shop.

HELICAL SPRINGS.

The spring which is usually designated "The Spiral Spring" has the form of a helix: this form is necessary where it is to be used as an accurate means for measuring force, the deflection of the helix being constant for equal loads.

In these springs the coils are closed in the normal position if it is to be subjected to tension in the direction of its axis; if it is to be used as a pressure organ, the coils are not in contact in this position.

Accuracy in the measurement of a force presupposes that the tension organ should be used; for during extension it preserves almost the true helical form and the coils remain in the cylindrical surface; but during compression, the spring, if long, is apt to buckle, and thus lose its proper figure. In the latter case, it is kept approximately in figure by being enclosed in a cylindrical casing, or held in position by a rod passing through the axis of the helix, which should be of such dimensions as not to impede the longitudinal motion of the spring. In making tests with helical springs, the diameter of the interior of the pipe which enclosed them was one quarter inch greater than the outside diameter of the coils; thus giving one eighth play all around between the spring and the pipe.

When there is danger that the spring may be subjected to a pressure greater than its intended bearing capacity, the pressure organ is to be used in preference to the tension organ; in the first case, if the coils be pressed home the spring is not necessarily broken; in the latter case if the loads are very great the spring must uncoil itself or break.

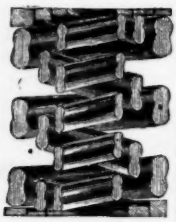
The form of the cross section as already mentioned is generally circular; because the action of the spring depends upon the torsion of the wire, and the laws of torsion are known with greater precision for a circular form of section than for any other.

The springs used upon railways are always compressed, and it is found best to place them in such a way, that the weight will be distributed equally over the entire circumference of the extremity of the cylindrical surface formed by the helix:

This can be done by tapering the ends of the rod before coiling, in such a manner that when the spiral is completed it is terminated by a plain annular surface at each extremity, so that if placed endwise upon a flat plate its axis will be perpendicular to the plate: the same end is attained by putting a casting on each extremity of the spring, in such a manner that it will fulfill with them the same conditions as mentioned above.

The first method is represented in Fig. 1, the second in Fig. 2. The springs are made of fluted steel; their bearing or sustaining power being considered, by some authorities, greater than if the wire were round. A portion of the steel is removed on the line of the neutral axis and put in the heads of the bar giving it greater tempering surface. It consists of two or more helical

FIG. 1. FIG. 2.



coils placed one within the other, forming a nest. The coils do not come in contact, and are consequently free from any friction whatever, while their sustaining power is materially increased. While acting in conjunction they have each a free and independent action, without abrasion; the full and proper power of each coil, being brought into requisition, producing easy, elastic and uniform action without wearing the spring. When the metallic surfaces of a spring come into contact, so as to produce friction, the usefulness of the spring is impaired in a corresponding degree.

FIG. 3.

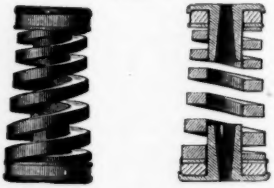
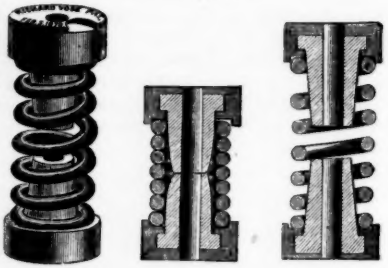


Fig. 3 represents a spring composed of a bar of steel that tapers in width or thickness or both from end to end, with a packing of India rubber at each end, supporting the light load on the apex; as the load increases the lighter coils close, bringing into requisition the heavier coils or base of the spring. This spring fills a want long felt for one that can be used for light or heavy loads as on railway cars.

We have also the helical cluster spring, consisting of a group of (6) six or (7) seven springs in a case of round or oblong form, as may be desired, in Fig. 5.

The *helical spring* is made by coiling a steel wire or rod of the required size, on a cylindrical mandrel, to the requisite pitch and length, tempering and testing it. The *modus operandi* is essentially the same—from the heavy car spring, weighing over sixty pounds to the delicate hair spring of the watch.

FIGS. 4.

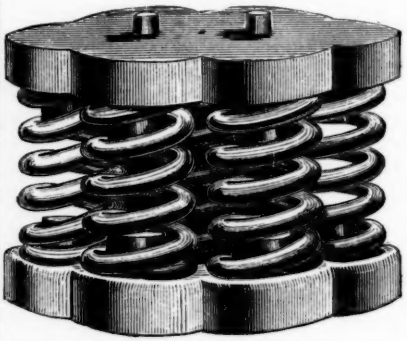


Elevation. Exhausted. Section.

Figs. 4 represent the Vose Graduated Spring for City Railway Cars. It is so constructed that the spiral alone carries the empty car, and as the load increases, the elastic cones are brought into requisition, the whole gradually accumulating power without friction or abrasion, imparting a soft, easy motion. It has been thoroughly tested, and answers its requirements in every particular.

The steel is generally heated to redness before coiling, but sometimes is coiled cold. The essential difference between the machines for coiling consists in the guide gauge for the wire.

FIG. 5.



The operation is as follows: the heated rod is taken from the oven or furnace, pinched upon the mandrel by means of a dog, and when the machine begins operations a jaw, driven by a screw feed, siezes the rod and guides it so as to produce a helix of the required

pitch and length; sometimes the jaw is dispensed with and the steel made to take its proper form by sliding directly on the worm. A machine now in use in a Newark spring factory consists of an iron frame about four feet high carrying a shaft with a pulley, by means of which power is applied. This shaft, by interposition of gears, turns the mandrel on which the spring is wound, and also the guide curves. These guide curves are in front of the coiling mandrel, the axes of the two being parallel. By means of a lever, the mandrel may be drawn out of its position in a direction along its axis, in which movement the coil strikes a tappet projecting from above, and the spring is thus stripped from the mandrel. The spring is held upon the mandrel by a small dog, shaped like a hook, which grasps the steel.

TEMPERING.

When steel is heated to a high temperature and suddenly cooled it is hardened; when the temperature is gradually lowered it is softened; between these two extremes any degree of hardness may be obtained.

Spring steel being generally hard when it leaves the manufacturer, the spring maker's first care is to heat it to facilitate him in his work of coiling and shaping it; this process necessarily softens the material and renders a re-hardening requisite to give it the proper temper. The majority of manufacturers temper their springs in oil baths. The oil is kept at the proper temperature by cold water circulating through pipes that run through and around the reservoir; or it may be kept cool by being forced through a perforated plate and, falling into a chamber, meeting a current of cool air coming from an opposite direction. Economy in oil may thus be practiced and with equally satisfactory results. The springs are cleaned by placing them in a revolving cylinder, partly filled with sawdust; or by being introduced into a solution of potash.

The ovens for heating the springs before coiling and tempering are usually three in number, and are made of fire-brick: the coke used is directly under the lowest of the three, and the heat passes, in its upward course, under and around the other two, thus producing three separate and distinct temperatures, which enable us to obtain with certainty three grades of hardness.

The ovens are so constructed as to heat the steel without burning, keeping all the good qualities and not subjecting it to chemical deterioration. These ovens have their retorts vertically above each other, and the furnace, which is under the lowest one, has its fire-door on the front side with the doors of the retorts.

Another form of oven may be constructed as follows: there are four brick walls with a roof and chimney, the section is a square, the sides of which are twelve feet in length, and the walls are eight feet in height. The wall which forms the front has an iron plate bolted to it in which there are three apertures provided with iron doors; these iron doors open to the retorts in which the steel is heated. The retorts are twelve feet long and semi-circular in section, the diameter of the section is about two feet, the wall opposite has a door opening to the furnace within, the oven being thus fired from behind. The grate is fifteen inches in width and feet long; the flame and heated gas pass from the grate around one of the retorts, and in their return around the other two (the center one being a little above the level of the other two), and then pass into the chimney; the retorts are lined with fire-brick; the chimney whose outside cross section is about two feet square, is four feet high, and is provided with a smoke pipe, one foot in diameter and fifteen feet high; the oven and chimney are provided with buck staves, which are held by one inch bolts: the oven is provided with hand holes for cleaning.

In the manufacture of springs, the retorts are sometimes dispensed with, and the springs are placed directly on the coke; nor are they always re-heated after working and before tempering, but are placed directly in the oil after leaving the mandrel. It is admitted, however, that the use of the retorts and the re-heating before tempering are the preferable methods, the results being much surer.

In some shops a second tempering is given in lead baths; this seems to be a kind of annealing and is rarely used; the

spring is plunged into molten lead and kept there till its temperature equals that of the lead; then cooled gradually in the open air.

The *Scientific Record* says that springs are generally hardened by being immersed in various compositions of oil, suet, wax and like materials, and, after being taken from the composition, held over a clear coke fire till the grease inflames: this is called "blazing off."

A greatly recommended composition consists of two lbs. of suet, and a quarter lb. of bees wax to every gallon of whale oil. These are boiled together and will serve for thin articles and most kinds of steel; the addition of black resin, to the extent of about one pound to the gallon, makes it sure for thicker pieces, and for those it refused to harden on the first trial; the composition becomes useless after it has been constantly employed for about a month; the period, however, depends upon the extent to which it has been used; the trays should be thoroughly cleansed before a new mixture is placed in them. The following is also recommended:

20 gallons spermaceti oil.
20 lbs. melted and strained beef suet.
1 gallon neats-foot oil.
1 lb. pitch.
3 lbs. black resin.

The last two articles must be previously melted together and then added to the other ingredients; the whole must then be heated in a proper iron vessel fitted with a close cover, until the moisture is entirely evaporated, and the composition will take fire upon a flaming body being presented to its surface. For a *spring temper* the whole of the fatty composition must burn away from its surface, if the work is thick; or if unequally thick and thin, as in some springs, a second and third dose is burned off to insure equality of temperature at all points alike.

Gun lock springs are sometimes literally fried in oil for a considerable time over a fire in an iron tray; the thick parts are then sure to be sufficiently reduced, and the thin parts do not become the more softened from the continuance of the blazing heat.

Springs do not appear to lose their elasticity, after the hardening and tempering, from the reduction they are compelled to undergo in grinding and polishing.

TESTING MACHINES.

There are a variety of testing machines. Hydraulic presses are at times used. The principal part of the hydraulic press is a ram, which carries the table on which the spring to be used is placed. On top of the machine is a lever to be weighted with any desirable load at the other end. The load rests on a support, until the pressure of the ram under the spring is great enough to lift the lever and its weight at the extremity. Thus the lever and the weight gauge the pressure to which the spring is subjected. Steam power is used for working the pump which raises the ram.

Another form of machine consists of a table worked by a screw from below. The springs are loaded by means of a lever.

A third one which is extensively used consists of a platform sliding vertically; this platform is supported by a stout iron rod and is worked from below by means of a connecting rod and crank, a lever measures the pressure on the spring.

These three machines give the behavior of the springs when subjected to pressure only a few times. In practice a spring is subjected to pressure till it is worthless; hence the above tests give no idea of the endurance of a spring.

In Europe spring testers for the latter information consist of slotting machines under which the springs are placed; the stroke of the head is made equal to the action of the spring; thus by every stroke the spring is compressed. A counter attached to the machine gives the number of strokes, and consequently the endurance.

The following is the method to be pursued when springs are made in a machine shop. It is the substance of an article on the manufacture of helical springs by Mr. Rose, in the *Scientific American, Supt. No.* 20, May 13, 1876.

The means employed are a lathe and a mandrel with a groove. In the regular coiling machines the mandrels are plane and the wire is guided by separate guide curves.

The mandrel for forming a brass spring has a helical groove of the proper pitch,

of less diameter than the spring, and a little longer to make room for the lathe dog.

On one end is placed a washer rather larger than the outside diameter of the spring when secured upon the mandrel, and provided with a keyway and key; slipping the washer over, the mandrel is placed in the lathe between the centers and the loose washer slid back against its dead center; the end of the spring wire is passed through the hole in the mandrel and pulled close, bending it over the corner of the hole, and tapped lightly with a hammer. Holding the wire firmly against the mandrel, the lathe is started and the spring wound, taking care that it winds closely. When wound to the requisite length the washer is slipped up and the key driven home and the wire cut. Placing the mandrel, with the spring, on an iron block, the spring is hammered, setting the wire to the mandrel and hardening the brass. It is important to hammer and set the wire to its form; otherwise it would uncoil to a spring of larger diameter and less length; the mandrel should not be hammered while on the centers, they might be injured and the mandrel bent.

If the wire is too stiff to be held against the mandrel by hand, the gearing (if the lathe is a self-acting one) necessary to cut a thread, of the same pitch as that of the required spring, is put on and a grooved piece of metal is fastened into the tool post, which acts as a guide. If the lathe is not self-acting and has a hand slide rest, the screw feed is taken from the straight feed of the rest and the metal guide used, allowing the groove to carry the wire along; the groove being in this case three-eighth as deep as the of ameter of the wire; and if of iron or brass it is taken to the anvil and hammered all over its circumference equally and evenly, with blows at not more than one-fourth inch apart, otherwise there cannot be maintained any definite relation between the size of the mandrel and that of the spring; but if of steel, the mandrel and the spring must be heated together to a low, red heat, to set the spring to the mandrel, as the hammering in this case would only close the grain and add to its elasticity without having much effect in making it hug the mandrel, except in case of very small wire.

HARDENING.

Springs of light wire, or those long in proportion to their diameter, should be placed on a mandrel fitting loosely and heated while on it to prevent bending and disarrangement of the coils during the heating process. The fire should be clear, of green coal; some times a fire is built around a piece of gas pipe, with the spring inserted; this causes the spring to be uniformly heated. Being heated to a cherry red, the spring must be plunged into clear water slightly heated, and held there till quite cold.

If it is then found black and not evenly mottled with white spots it would indicate an insufficient hardness arising from the quality of the steel or insufficient heating; steel when of good quality is sufficiently heated when it just forms scales on coming from the fire.

If the hardening process is found difficult, the water should be salted till it becomes a strong brine and the hardening repeated till the steel appears white when taken out of the water, as it will if well hardened; the whiteness of the surface being a better test than the file would be, because steel of a straw color will not file, and any degree of hardness, between straw color and white cannot be distinguished by this test.

The temper of a spring, lowered from a white hardness to a blue, is not the same as that lowered from a black or even a mottled hardness to a blue, and hence for the sake of evenness in the temper, all those of a dark or mottled appearance should be reheated.

TEMPERING.

The most reliable method of tempering an ordinary spring, is to "blaze it off:" *i. e.* fry or boil it off in the oil, heating and reheating the oil to a blaze, and dipping and redipping it in two or three times; after the boiling and the blazing takes place freely all over the spring, and has, on the last removal from the tank, burned out at any one point it should be placed in warm water and left to cool.

The thicker the spring the longer it should be subjected to this process of blazing and dipping, so that every part of the spring shall be equally heated inside and out. It is well

that the spring should be reversed and revolved in the oil, that it should not accumulate at any one point and thus make an uneven temper. A good oil composition consists of

Spermaceti oil	one gallon.
Neats foot oil.....	one gallon.
Rendered beef suet.	one pound.
Resin	quarter pound.

The tank should have a close fitting cover which will put out the blaze when the tempering is finished.

THE HELICAL BALANCE SPRING of a watch is made from drawn steel wire, giving the material the necessary form and fastening it so as to be capable of further manipulation; the spring is subjected to a heat sufficient to turn the wire blue, when it will retain its shape, or it may be subjected directly to the fire which makes it more durable. The mode of operation is simple, and is as follows: the wire is wound upon a hollow cylinder which is smooth or grooved, the thickness not being more than one-eighth of its diameter, otherwise it would cool too slowly. The cylinder with the spring is placed in an iron box which has a loose cover, the inner space being about three times the diameter of the spring and somewhat deeper; the box is filled with powdered charcoal mixed with powdered ivory, and the whole heated to a yellow heat in which it is kept one minute. It is then reversed over a vessel of oil, the loose top and cylinder falling into it. It will be evenly heated throughout and never change its form, a contingency which sometimes happens when water is used. At times platina foil is wrapped around the spring to exclude the air, it can then be heated on a piece of charcoal by means of a blowpipe; for hardening cold water is used in this case.

APPLICATION OF RUBBER.

In building railway cars the effect of two kinds of movements have to be considered.

1st. Jolts and shocks: a shock is produced by the impinging of one mass against another, whereby the velocity of one or both of the masses is suddenly changed, or in common parlance, it is a blow produced by one solid body striking another.

Railway springs resist shocks, as bearing springs which diminish shock between rail and wheel, as buffer springs intended to reduce the effect of shock in the direction of the train's length, and as traction springs, intended to reduce the shock in traveling and prevent the breaking of connections. The springs used should be sensitive; that is to say of rapid action. They should yield through a sufficient space in proportion to the jolt; for if a moving mass be brought to rest by a resistance acting through a certain space, the longer the space the less the shock.

2d. What are known as jars or tremors which are produced by forces moving with great rapidity through very small spaces. The jolts or shocks can be met by a spring made of steel, but the jars are so much more rapidly propagated than the time which the spring requires to move, that they are transmitted through the steel spring exactly as if it were a rigid body. Rubber, by yielding instantaneously to the pressure, takes up the jar; consequently when both movements are to be encountered, a combination of rubber and steel is necessary. Rubber has been used with helical springs for another reason. When a helical spring is subjected to a pressure it increases its resistance, when its limit of loading is approached; but the resistance does not, at times, increase rapidly enough to prevent a shock which happens when the spring is subjected to so great a load as to close the coils. This shock often breaks the spring. The difficulty is overcome by placing a core of rubber within the helix; now, when the spring is compressed, the rubber is compressed also and necessarily bulges out laterally, thus forming a cushion between the coils. The resistance of the cushion increases rapidly with the shortening of the spring, and produces an almost insensible transition from the free yielding, to the absolute cessation of motion which occurs when the coils touch each other.* The combination would do very well were it not for the fact that the rubber under this condition is soon destroyed.

The bulging out of the rubber is necessary for the preservation of the elasticity of the core, but it must not be accom-

* G. W. Robertson, Class of 1876.

FIG. 6.

panied by abrasion. Rubber confined is, so to say, not elastic; the experiment has been tried of placing a rubber cylinder of the same density as that used for car springs in an aperture made in a stout piece of steel, and subjecting it longitudinally to pressure. It was found to have very little elasticity. Fig. 6 represents a rubber center helical spring; the hole through the center allows it to expand and contract without abrasion; its action is uniform and it is not affected by moisture. The following shows the elasticity of Vose, Dinsmore & Co.'s rubber center helical springs of a length equal to $5\frac{1}{2}$ inches and diameter of $2\frac{1}{8}$ inches, and the number required for carrying various loads, the diameter of the wire being $\frac{11}{32}$ inches.

The first horizontal line of figures in the table gives the deflection in inches produced by any load, given in the vertical column beneath the recorded deflection, for the number of springs given in the first vertical column.

LOAD IN GROSS TONS.

10-Coil Rubber Center Spiral Springs.					Maximum Working Load.						Weight of Springs per load to be Carried.
Elasticity in Ins.	0.27	0.45	0.67	0.83	0.98	1.09	1.16	1.22	1.28	1.33	Lbs.
2 Springs with rubber centers	0.223	0.446	0.669	0.893	1.116	1.339	1.562	1.785	2.008	2.232	3.75
4 " "	0 446	0.892	1.338	1.786	2.232	2.678	3.124	3.575	4.016	4.464	7.50
6 " "	0.669	1.338	2.007	2.679	3.348	4.017	4.680	5.355	6.024	6.696	11.25
8 " "	0.892	1.784	2.676	3.572	4.464	5.356	6.248	7.140	8.032	8.928	15.00
10 " "	1.115	2.230	3.345	4.465	5.580	6 695	7.810	8.925	10.040	11.160	18.75
12 " "	1.338	2.676	4.014	5.358	6.696	8.034	9.372	10.710	12.048	13.392	22.50
14 " "	1.561	3.122	4.683	6.251	7.812	9.373	10.934	12.495	14.056	15.624	26.25
16 " "	1.784	3.568	5.352	7.144	8.928	10.712	12.496	14.280	16.064	17.856	30.00
18 " "	2.007	4.014	6.021	8.037	10.044	12.051	14.058	16.065	18.072	20.078	33.75
20 " "	2.230	4.46	6.69	8.93	11.16	13.39	15.62	17.85	20.080	22.320	37.50
22 " "	2.453	4.90	7.66	9.82	12.27	14.72	17.18	19.63	22.088	24.552	41.25
24 " "	2.676	5.35	8.02	10 71	13.39	16.06	18 74	21.42	24.096	26.784	45.00
26 " "	2.899	5.80	8.69	11.61	14.50	17.40	20.30	23.20	26.104	29.016	48.75
28 " "	3.122	6.24	9.36	12.50	15.62	18.74	21.86	25.00	28.112	31.248	52.50
30 " "	3.345	6.69	10.03	13.39	16.74	20.08	23.43	26.77	30.120	33.480	56.25
32 " "	3.568	7.13	10.70	14.28	17.85	21.42	25.00	28.56	32.128	35.712	60.00
34 " "	3.791	7.58	11.37	15.18	18.97	22.76	26.56	30.34	34.136	37.944	63.75
36 " "	4.014	8.02	12.04	16.07	20.08	24.10	28.12	32.13	36.144	40 176	67.50
38 " "	4.237	8.47	12.71	16.87	21.20	25.44	29.67	33.91	38.152	42.408	71.25
40 " "	4.460	8.92	13.38	17.86	22.32	26.78	31.24	35.70	40.160	44.640	75.00
44 " "	4.906	9.81	14.71	19.64	24.55	29.45	34.36	39.27	44.176	49.104	82.50
48 " "	5.352	10.70	16.05	21.43	26.78	32.13	37.48	42.84	48.192	53.568	90 00

The above calculations are based upon Tests made by Mr. David Kirkaldy, at his Testing Works, Southwark, England.

DURATION OF STEEL AND IRON RAILS.

From "Iron."

THE following figures refer to the main line of the Cologne-Minden railway, which has a total length of way of 1357 miles, or double that length of rails in use, exclusive of colliery sidings. At the end of 1876 more than 90 per cent. of the whole was laid with steel, the substitution for iron having been in progress since 1864. The effect of this on the maintenance of the line is seen in the following table:

Renewals in	1870,	7.75	per cent. of total length.
"	1871,	8.77	" "
"	1872,	7.55	" "
"	1873,	8.40	" "
"	1874,	4.33	" "
"	1875,	1.04	" "
"	1876,	1.13	" "

The rate at which the actual substitution of steel for iron proceeded is given in the following table, representing the number of Bessemer steel rails laid down and removed in each year since 1868:

Year.	No. of rails in use at end of year.	No. of rails laid during year.	Removed as useless during year.	Percentage of length in use.	Rails broken before laying.
1868	1,853				
1869	21,867	20,014	31	0.142	No. 3
1870	78,259	56,392	20	0.025	" 4
1871	139,618	61,359	54	0.039	" 18
1872	222,844	83 226	93	0.042	" 41
1873	340,300	117,456	342	0.101	"173
1874	452,650	112,350	738	0.158	" 8
1875	504,634	51,984	347	0.069	" 2
1876	514,801	10,167	310	0.060	" 2
			1,935	0.376	251= 0.049 per cent.

Out of the total of 1935 rails rendered unserviceable, 1204 broke through the full section, 227 through the fish-bolt holes, and 504 were otherwise damaged. That the number of removals does not increase, but has substantially diminished since 1874, is accounted for by the fact that these removals are necessitated not so much by wear as by defects in manufacture, which are usually discovered within a short time after the rail has been laid.

In order to obtain accurate data as to the comparative efficiency of different classes of rails, a number of samples from different makers were laid on a part of the line having the heaviest traffic, near the Oberhausen station. The experiment commenced in 1864, and the results obtained up to the end of 1876 were as follows. The rails were all of the same section, called Calibre IV., and 5650 millimeters area:

Description of rail.	Laid in 1864	Remaining in 1876.	Average wear of head.	Removals in twelve years.	
	No.	No.	Mil.	No.	Per cent.
Fine-grained iron from Friedrich-Wilhelm Hutte, Troisdorf	150	29	..	121	80.66
Case-hardened iron from Phenix-Hutte	150	48	4.44	102	68.00
Puddle steel, Funke & Co., Hagen	12	8	4.72	4	33.33
Puddle steel, E. Hosch & Sons, Lendersdorf	12	8	4.72	4	33.33
Bessemer steel, E. Hosch & Sons	149	142	5.22	7	4.70
Bessemer steel, F. Krupp	147	141	5.18	6	4.08
Bessemer steel, Horder Verein	150	148	4.18	2	1.33

The average wear of the experimental Bessemer rails is 4.86, which represents the effect produced by the passage of 6,500,000 axles of passenger and goods trains, or about 1,340,000 axles for each millimeter of wear.

MATTER AND MOTION.

By J. CLERK MAXWELL, LL.D., F.R.S.

II.

CHAPTER V.

ON WORK AND ENERGY.

DEFINITIONS.—Work *is the act of producing a change of configuration in a system in opposition to a force which resists that change.*

Energy *is the capacity of doing work.*

When the nature of a material system is such that if, after the system has undergone any series of changes, it is brought back in any manner to its original state, the whole work done by external agents on the system is equal to the whole work done by the system in overcoming external forces, the system is called a CONSERVATIVE SYSTEM.

PRINCIPLE OF CONSERVATION OF ENERGY.—The progress of physical science has led to the discovery and investigation of different forms of energy, and to the establishment of the doctrine that all material systems may be regarded as conservative systems, provided that all the different forms of energy which exist in these systems are taken into account.

This doctrine, considered as a deduction from observation and experiment can, of course, assert no more than that no instance of a non-conservative system has hitherto been discovered.

As a scientific or science-producing doctrine, however, it is always acquiring additional credibility from the constantly increasing number of deductions which have been drawn from it, and which are found in all cases to be verified by experiment.

In fact the doctrine of the Conservation of Energy is the one generalized statement which is found to be consistent with fact, not in one physical science only, but in all.

When once apprehended it furnishes to the physical inquirer a principle on which he may hang every known law relating to physical actions, and by which he may be put in the way to discover the relations of such actions in new branches of science.

For such reasons the doctrine is commonly called the Principle of the Conservation of Energy.

GENERAL STATEMENT OF THE PRINCIPLE OF THE CONSERVATION OF ENERGY.—*The total energy of any material system is a quantity which can neither be increased nor diminished by any action between the parts of the system, though it may be transformed into any of the forms of which energy is susceptible.*

If, by the action of some agent external to the system, the configuration of the system is changed, while the forces of the system resist this change of configuration, the external agent is said to do work on the system. In this case the energy of the system is increased by the amount of work done on it by the external agent.

If, on the contrary, the forces of the system produce a change of configuration which is resisted by the external agent, the system is said to do work on the external agent, and the energy of the system is diminished by the amount of work which it does.

Work, therefore, is a transference of energy from one system to another; the system which gives out energy is said to do work on the system which receives it, and the amount of energy given out by the first system is always exactly equal to that received by the second.

If, therefore, we include both systems in one larger system, the energy of the total system is neither increased nor diminished by the action of the one partial system on the other.

MEASUREMENT OF WORK.—Work done by an external agent on a material system may be described as a change in the configuration of the system taking place under the action of an external force tending to produce that change.

Thus, if one pound is lifted one foot from the ground by a man in opposition to the force of gravity, a certain amount of work is done by the man, and this quantity is known among engineers as one foot-pound.

Here the man is the external agent, the material system consists of the earth and the pound, the change of configuration is the increase of the distance between the matter of the earth and the matter of the pound, and the force is the upward force exerted by the man in lifting the pound, which is equal and opposite to the weight of the pound. To raise the pound a foot higher would, if gravity were a uniform force, require exactly the same amount of work. It is true that gravity is not really uniform, but diminishes as we ascend from the earth's surface, so that a foot-pound is not an accurately know quantity, unless we specify the intensity of gravity at the place. But for the purpose of illustration we may assume that gravity is uniform for a few feet of ascent, and in that case the work done in lifting a pound would be one foot-pound for every foot the pound is lifted.

To raise twenty pounds of water ten feet high requires 200 foot-pounds of work. To raise one pound ten feet high requires ten foot-pounds, and as there are twenty pounds the whole work is twenty times as much, or two hundred foot-pounds.

The quantity of work done is, therefore, proportional to the product of the numbers representing the force exerted and the displacement in the direction of the force.

In the case of a foot-pound the force is the weight of a pound—a quantity which, as we know, is different in different places. The weight of a pound expressed in absolute measure is numerically equal to the intensity of gravity, the quantity denoted by g, the value of which in poundals to the pound varies from 32.227 at the pole to 32.117 at the equator, and diminishes without limit as we recede from the earth. In dynes to the gramme it varies from 978.1 to 983.1. Hence, in order to express work in a uniform and consistent manner, we must multiply the number of foot-pounds by the number representing the intensity of gravity at the place. The work is thus reduced to foot-poundals. We shall always understand work to be measured in this manner and reckoned in foot-poundals when no other system of measurement is mentioned. When work is expressed in foot-pounds the system is that of *gravitation-measures*, which is not a complete system unless we also know the intensity of gravity at the place.

In the metrical system the unit of work is the Erg, which is the work done by a dyne acting through a centimeter. There are 421393.8 ergs in a foot-poundal.

Potential Energy.—The work done by a man in raising a heavy body is done in overcoming the attraction between the earth and that body. The energy of the material system, consisting of the earth and the heavy body, is thereby increased. If the heavy body is the leaden weight of a clock, the energy of the clock is increased by winding it up, so that the clock is able to go for a week in spite of the friction of the wheels and the resistance of the air to the motion of the pendulum, and also to give out energy in other forms, such as the communication of the vibrations to the air, by which we hear the ticking of the clock.

When a man winds up a watch he does work in changing the form of the mainspring by coiling it up. The energy of the mainspring is thereby increased, so that as it uncoils itself it is able to keep the watch going.

In both these cases the energy communicated to the system depends upon a change of configuration.

Kinetic Energy.—But in a very important class of phenomena the work is done in changing the velocity of the body on which it acts. Let us take as a simple case that of a body moving without rotation under the action of a force. Let the mass of the body be M pounds, and let a force of F poundals act on it in the line of motion during an interval of time, T seconds. Let the velocity at the beginning of the interval be V and that at the end V′ feet per second, and let the distance traveled by the body during the time be S feet. The original momentum is MV, and the final momentum is MV′, so that the increase of momentum is M (V′−V), and this, by the second law of motion is equal to FT, the *impulse* of the force F acting for the time T. Hence

$$FT=M\,(V'-V). \qquad (1)$$

Since the velocity increases uniformly

with the time, the mean velocity is the arithmetical mean of the original and final velocities, or $\frac{1}{2}(V'+V)$.

We can also determine the mean velocity by dividing the space S by the time T, during which it is described.

$$\text{Hence } \frac{S}{T}=\tfrac{1}{2}(V'+V). \qquad (2)$$

Multiplying the corresponding members of equations (1) and (2) each by each we obtain—

$$FS=\tfrac{1}{2}MV''^2-\tfrac{1}{2}MV^2 \qquad (3)$$

Here FS is the work done by the force F acting on the body while it moves through the space S in the direction of the force, and this is equal to the excess of $\frac{1}{2}MV''^2$ above $\frac{1}{2}MV^2$. If we call $\frac{1}{2}MV^2$, or half the product of the mass, into the square of the velocity, the *kinetic energy* of the body at first, then $\frac{1}{2}MV''^2$ will be the kinetic energy after the action of the force F through the space S. The energy is here expressed in foot-poundals.

We may now express the equation in words by saying that the work done by the force F in changing the motion of the body is measured by the increase of the kinetic energy of the body during the time that the force acts.

We have proved that this is true when the interval of time is so small that we may consider the force as constant during that time, and the mean velocity during the interval as the arithmetical mean of the velocities at the beginning and end of the interval. This assumption, which is exactly true when the force is constant, however long the interval may be, becomes in every case more and more nearly true as the interval of time taken becomes smaller and smaller. By dividing the whole time of action into small parts, and proving that in each of these the work done is equal to the increase of the kinetic energy of the body, we may, by adding the successive portions of the work and the successive increments of energy, arrive at the result that the total work done by the force is equal to the total increase of kinetic energy.

If the force acts on the body in the direction opposite to its motion, the kinetic energy of the body will be diminished instead of being increased, and the force, instead of doing work on the body, will act as a resistance, which the body, in its motion, overcomes. Hence a moving body, as long as it is in motion, can do work in overcoming resistance, and the work done by the moving body is equal to the diminution of its kinetic energy, till at last, when the body is brought to rest, its kinetic energy is exhausted, and the whole work it has done is then equal to the whole kinetic energy which it had at first.

We now see the appropriateness of the name *kinetic energy*, which we have hitherto used merely as a name to denote the product $\frac{1}{2}MV^2$. For the energy of a body has been defined as the capacity which it has of doing work, and it is measured by the work which it can do. The *kinetic* energy of a body is the energy it has in virtue of being in *motion*, and we have now shown that its value is expressed by $\frac{1}{2}MV^2$ or $\frac{1}{2}MV\times V$, that is, half the product of its momentum into its velocity.

Oblique Forces.—If the force acts on the body at right angles to the direction of its motion it does not work on the body, and it alters the direction but not the magnitude of the velocity. The kinetic energy, therefore, which depends on the square of the velocity, remains unchanged.

If the direction of the force is neither coincident with, nor at right angles to, that of the motion of the body we may resolve the force into two components, one of which is at right angles to the direction of motion, while the other is in the direction of motion (or in the opposite direction).

The first of these components may be left out of consideration in all calculations about energy, since it neither does work on the body nor alters its kinetic energy.

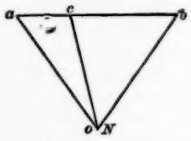
The second component is that which we have already considered. When it is in the direction of motion it increases the kinetic energy of the body by the amount of work which it does on the body. When it is in the opposite direction the kinetic energy of the body is diminished by the amount of work which the body does against the force.

Hence in all cases the increase of kinetic energy is equal to the work done on

the body by external agency, and the diminution of kinetic energy is equal to the work done by the body against external resistance.

KINETIC ENERGY OF TWO PARTICLES REFERRED TO THEIR CENTER OF MASS.—The kinetic energy of a material system is equal to the kinetic energy of a mass equal to that of the system moving with the velocity of the center of mass of the system, together with the kinetic energy due to the motion of the parts of the system relative to its center of mass.

FIG. 10.



Let us begin with the case of two particles whose masses are A and B, and whose velocities are represented in the diagram of velocities by the lines $o\ a$ and $o\ b$. If c is the center of mass of a particle equal to A placed at a, and a particle equal to B placed at b, then $o\ c$ will represent the velocity of the center of mass of the two particles.

The kinetic energy of the system is the sum of the kinetic energies of the particles, or

$$T=\tfrac{1}{2}\ A\ \overline{oa}^2+\tfrac{1}{2}\ B\ \overline{ob}^2.$$

Expressing $\overline{oa}^2$ and $\overline{ob}^2$ in terms of $o\ c$, $c\ a$ and $c\ b$ and the angle $o\ c\ a=\theta$.

$$T=\tfrac{1}{2}\ A\ \overline{oc}^2+\tfrac{1}{2}\ A\ \overline{ca}^2-A\ o\ c.c\ a\cos\theta.$$
$$+\tfrac{1}{2}\ B\ \overline{oc}^2+\tfrac{1}{2}\ B\ \overline{cb}^2-B\ o\ c.c\ b\ cos\ \theta.$$

But since c is the center of mass of A at a, and B at b,

$$A.\ \overline{ca}+B\ \overline{cb}=0.$$

Hence adding

$$T=\tfrac{1}{2}\ (A+B)\ \overline{oc}^2+\tfrac{1}{2}\ A\ \overline{ca}^2+\tfrac{1}{2}\ B\ \overline{cb}^2,$$

or, the kinetic energy of the system of two particles A and B is equal to that of a mass equal to (A + B) moving with the velocity of the center of mass, together with that of the motion of the particles relative to the center of mass.

KINETIC ENERGY OF A MATERIAL SYSTEM REFERRED TO ITS CENTER OF MASS.—We have begun with the case of two particles, because the motion of a particle is assumed to be that of its center of mass, and we have proved our proposition true for a system of two particles. But if the proposition is true for each of two material systems taken separately, it must be true of the system which they form together. For if we now suppose oa and ob to represent the velocities of the centers of mass of two material systems A and B, then $o\ c$ will represent the velocity of the center of mass of the combined system A+B, and if T_A represents the kinetic energy of the motion of the system A relative to its own center of mass, and T_B the same for the system B, then if the proposition is true for the systems A and B taken separately, the kinetic energy of A is

$$\tfrac{1}{2}\ A\ \overline{oa}^2+T_A,$$

and that of B

$$\tfrac{1}{2}\ B\ \overline{ob}^2+T_B.$$

The kinetic energy of the whole is, therefore,

$$\tfrac{1}{2}\ A\ \overline{oa}^2+\tfrac{1}{2}\ B\ \overline{ob}^2+T_A+T_B,$$

or,

$$\tfrac{1}{2}\ (A+B)\overline{oc}^2+\tfrac{1}{2}A\overline{ca}^2+T_A+\tfrac{1}{2}B\overline{cb}^2+T_B.$$

The first term represents the kinetic energy of a mass equal to that of the whole system moving with the velocity of the center of mass of the whole system.

The second and third terms, taken together, represent the kinetic energy of the system A relative to the center of gravity of the whole system, and the fourth and fifth terms represent the same for the system B.

Hence if the proposition is true for the two systems A and B taken separately, it is true for the system compounded of A and B. But we have proved it true for the case of two particles; it is, therefore, true for three, four, or any other number of particles, and therefore for any material system.

The kinetic energy of a system referred to its center of mass is less than its kinetic energy when referred to any other point.

For the latter quantity exceeds the former by a quantity equal to the

kinetic energy of a mass equal to that of the whole system moving with the velocity of the center of mass relative to the other point, and since all kinetic energy is essentially positive, this excess must be positive.

AVAILABLE KINETIC ENERGY.—We have already seen in "The Motion of the Center of Mass," etc., that the mutual action between the parts of a material system cannot change the velocity of the center of mass of the system. Hence that part of the kinetic energy of the system which depends on the motion of the center of mass cannot be affected by any action internal to the system. It is therefore, impossible, by means of the mutual action of the parts of the system, to convert this part of the energy into work. As far as the system itself is concerned, this energy is unavailable. It can be converted into work only by means of the action between this system and some other material system external to it.

Hence if we consider a material system unconnected with any other system, its available kinetic energy is that which is due to the motions of the parts of the system relative to its center of mass.

Let us suppose that the action between the parts of the system is such that after a certain time the configuration of the system becomes invariable, and let us call this process the solidification of the system. We have shown that the angular momentum of the whole system is not changed by any mutual action of its parts. Hence if the original angular momentum is zero, the system, when its form becomes invariable, will not rotate about its center of mass, but if it moves at all will move parallel to itself, and the parts will be at rest relative to the center of mass. In this case, therefore, the whole available energy will be converted into work by the mutual action of the parts during the solidification of the system.

If the system has angular momentum, it will have the same angular momentum when solidified. It will therefore rotate about its center of mass, and will therefore still have energy of motion relative to its center of mass, and this remaining kinetic energy has not been converted into work.

But if the parts of the system are allowed to separate from one another in directions perpendicular to the axis o the angular momentum of the system, and if the system when thus expanded is solidified, the remaining kinetic energy of rotation round the center of mass will be less and less the greater the expansion of the system, so that by sufficiently expanding the system we may make the remaining kinetic energy as small as we please, so that the whole kinetic energy relative to the center of mass of the system may be converted into work within the system.

POTENTIAL ENERGY.—The potential energy of a material system is the capacity which it has of doing work depending on other circumstances than the motion of the system. In other words, potential energy is that energy which is not kinetic.

In the theoretical material system which we build up in our imagination from the fundamental ideas of matter and motion, there are no other conditions present except the configuration and motion of the different masses of which the system is composed. Hence in such a system the circumstances upon which the energy must depend are motion and configuration only, so that, as the kinetic energy depends on the motion, the potential energy must depend on the configuration.

In many real material systems we know that part of the energy does depend on the configuration. Thus the mainspring of a watch has more energy when coiled up than when partially uncoiled, and two bar magnets have more energy when placed side by side with their similar poles turned the same way than when their dissimilar poles are placed next each other.

ELASTICITY.—In the case of the spring we may trace the connection between the coiling of the spring and the force which it exerts somewhat further by conceiving the spring divided (in imagination) into very small parts or elements. When the spring is coiled up, the form of each of these small parts is altered, and such an alteration of the form of a solid body is called a Strain.

In solid bodies strain is accompanied

with internal force or stress; those bodies in which the stress depends simply on the strain are called Elastic, and the property of exerting stress when strained is called Elasticity.

We thus find that the coiling of the spring involves the strain of its elements, and that the external force which the spring exerts is the resultant of the stresses in its elements.

We thus substitute for the immediate relation between the coiling of the spring and the force which it exerts a relation between the strains and stresses of the elements of the spring; that is to say, for a single displacement and a single force, the relation between which may in some cases be of an exceedingly complicated nature, we substitute a multitude of strains and an equal number of stresses, each strain being connected with its corresponding stress by a much more simple relation.

But when all is done, the nature of the connection between configuration and force remains as mysterious as ever. We can only admit the fact, and if we call all such phenomena phenomena of elasticity, we may find it very convenient to classify them in this way, provided we remember that by the use of the word elasticity we do not profess to explain the cause of the connection between configuration and energy.

Action at a Distance.—In the case of the two magnets there is no visible substance connecting the bodies between which the stress exists. The space between the magnets may be filled with air or with water, or we may place the magnets in a vessel and remove the air by an air-pump, till the magnets are left in what is commonly called a vacuum, and yet the mutual action of the magnets will not be altered. We may even place a solid plate of glass or metal or wood between the magnets, and still we find that their mutual action depends simply on their relative position, and is not perceptibly modified by placing any substance between them, unless that substance is one of the magnetic metals. Hence the action between the magnets is commonly spoken of as *action at a distance.*

Attempts have been made, with a certain amount of success,* to analyze this action at a distance into a continuous distribution of stress in an invisible medium, and thus to establish an analogy between the magnetic action and the action of a spring or a rope in transmitting force; but still the general fact that strains or changes of configuration are accompanied by stresses or internal forces, and that thereby energy is stored up in the system so strained, remains an ultimate fact which has not yet been explained as the result of any more fundamental principle.

Theory of Potential Energy more Complicated than that of Kinetic Energy.—Admitting that the energy of a material system may depend on its configuration, the mode in which it so depends may be much more complicated than the mode in which the kinetic energy depends on the motion of the system. For the kinetic energy may be calculated from the motion of the parts of the system by an invariable method. We multiply the mass of each part by half the square of its velocity, and take the sum of all such products. But the potential energy arising from the mutual action of two parts of the system may depend on the relative position of the parts in a manner which may be different in different instances. Thus when two billiard balls approach each other from a distance, there is no sensible action between them till they come so near one another that certain parts appear to be in contact. To bring the centers of the two balls nearer, the parts in contact must be made to yield, and this requires the expenditure of work.

Hence in this case the potential energy is constant for all distances greater than the distance of first contact, and then rapidly increases when the distance is diminished.

The force between magnets varies with the distance in a very different manner, and in fact we find that it is only by experiment that we can ascertain the form of the relation between the configuration of a system and its potential energy.

Application of the Method of Energy to the Calculation of Forces.

* See Clerk Maxwell's "Treatise on Electricity and Magnetism," Vol. II., Art. 641.

—A complete knowledge of the mode in which the energy of a material system varies when the configuration and motion of the system are made to vary is mathematically equivalent to a knowledge of all the dynamical properties of the system. The mathematical methods by which all the forces and stresses in a moving system are deduced from the single mathematical formula which expresses the energy as a function of the variables have been developed by Lagrange, Hamilton, and other eminent mathematicians, but it would be difficult even to describe them in terms of the elementary ideas to which we restrict ourselves in this book. An outline of these methods is given in my treatise on Electricity, Part IV., Chapter V., Article 553, and the application of these dynamical methods to electro-magnetic phenomena is given in the chapters immediately following.

But if we consider only the case of a system at rest it is easy to see how we can ascertain the forces of the system when we know how its energy depends on its configuration.

For let us suppose that an agent external to the system produces a displacement from one configuration to another, then if in the new configuration the system possess more energy than it did at first, it can have received this increase of energy only from the external agent. This agent must therefore have done an amount of work equal to the increase of energy. It must therefore have exerted force in the direction of the displacement, and the mean value of this force, multiplied into the displacement, must be equal to the work done. Hence the mean value of the force may be found by dividing the increase of energy by the displacement.

If the displacement is large this force may vary considerably during the displacement, so that it may be difficult to calculate its mean value; but since the force depends on the configuration, if we make the displacement smaller and smaller the variation of the force will become smaller and smaller, so that at last the force may be regarded as sensibly constant during the displacement.

If, therefore, we calculate for a given configuration the *rate* at which the energy increases with the displacement, by a method similar to that described "On the Measurement of Velocity when Variable;" "Diagram of Velocities," and "On the Rate of Acceleration," this rate will be numerically equal to the force exerted by the external agent in the direction of the displacement.

If the energy diminishes instead of increasing as the displacement increases, the system must do work on the external agent, and the force exerted by the external agent must be in the direction opposite to that of displacement.

Specification of the Direction of Forces.—In treatises on dynamics the forces spoken of are usually those exerted by the external agent on the material system. In treatises on electricity, on the other hand, the forces spoken of are usually those exerted by the electrified system against an external agent which prevents the system from moving. It is necessary, therefore, in reading any statement about forces, to ascertain whether the force spoken of is to be regarded from the one point of view or the other.

We may in general avoid any ambiguity by viewing the phenomenon as a whole, and speaking of it as a stress exerted between two points or bodies, and distinguishing it as a tension or a pressure, an attraction or a repulsion, according to its direction, "Action and Reaction are the Partial Aspects of a Stress."

Application to a System in Motion.—It thus appears that from a knowledge of the potential energy of a system in every possible configuration we may deduce all the external forces which are required to keep the system in that configuration. If the system is at rest, and if these external forces are the actual forces, the system will remain in equilibrium. If the system is in motion the force acting on each particle is that arising from the connections of the system (equal and opposite to the external force just calculated), together with any external force which may be applied to it. Hence a complete knowledge of the mode in which the potential energy varies with the configuration would enable us to predict every possible motion of the system under the action of given external forces, provided we were able

to overcome the purely mathematical difficulties of the calculation.

Application of the Method of Energy to the Investigation of Real Bodies.—When we pass from abstract dynamics to physics—from material systems, whose only properties are those expressed by their definitions, to real bodies, whose properties we have to investigate—we find that there are many phenomena which we are not able to explain as changes in the configuration and motion of a material system.

Of course if we begin by assuming that the real bodies are systems composed of matter which agrees in all respects with the definitions we have laid down, we may go on to assert that all phenomena are changes of configuration and motion, though we are not prepared to define the kind of configuration and motion by which the particular phenomena are to be explained. But in accurate science such asserted explanations must be estimated, not by their promises, but by their performances. The configuration and motion of a system are facts capable of being described in an accurate manner, and therefore, in order that the explanation of a phenomenon by the configuration and motion of a material system may be admitted as an addition to our scientific knowledge, the configurations, motions, and forces must be specified, and shown to be consistent with known facts, as well as capable of accounting for the phenomenon.

Variables on which the Energy Depends.—But even when the phenomena we are studying have not yet been explained dynamically, we are still able to make great use of the principle of the conservation of energy as a guide to our researches.

To apply this principle, we in the first place assume that the quantity of energy in a material system depends on the state of that system, so that for a given state there is a definite amount of energy.

Hence the first step is to define the different states of the system, and when we have to deal with real bodies we must define their state with respect not only to the configuration and motion of their visible parts, but if we have reason to suspect that the configuration and motion of their invisible particles influence the visible phenomenon, we must devise some method of estimating the energy thence arising.

Thus pressure, temperature, electric potential, and chemical composition are variable quantities, the values of which serve to specify the state of a body, and in general the energy of the body depends on the values of these and other variables.

Energy in Terms of the Variables.—The next step in our investigation is to determine how much work must be done by external agency on the body in order to make it pass from one specified state to another.

For this purpose it is sufficient to know the work required to make the body pass from a particular state, which we may call the *standard state*, into any other specified state. The energy in the latter state is equal to that in the standard state, together with the work required to bring it from the standard state into the specified state. The fact that this work is the same through whatever series of states the system has passed from the standard state to the specified state is the foundation of the whole theory of energy.

Since all the phenomena depend on the variations of the energy of the body, and not on its total value, it is unnecessary, even if it were possible, to form any estimate of the energy of the body in its standard state.

Theory of Heat.—One of the most important applications of the principle of the conservation of energy is to the investigation of the nature of heat.

At one time it was supposed that the difference between the states of a body when hot and when cold was due to the presence of a substance called caloric, which existed in greater abundance in the body when hot than when cold. But the experiments of Rumford on the heat produced by the friction of metal, and of Davy on the melting of ice by friction, have shown that when work is spent in overcoming friction, the amount of heat produced is proportional to the work spent.

The experiments of Hirn have also shown that when heat is made to do work

in a steam-engine, part of the heat disappears, and that the heat which disappears is proportional to the work done.

A very careful measurement of the work spent in friction, and of the heat produced, has been made by Joule, who finds that the heat required to raise one pound of water from 39° F. to 40° F. is equivalent to 772 foot-pounds of work at Manchester, or 24,858 foot-poundals.

From this we may find that the heat required to raise one gramme of water from 3° C. to 4° C. is 42,000,000 ergs.

Heat a Form of Energy.—Now, since heat can be produced it cannot be a substance; and since whenever mechanical energy is lost by friction there is a production of heat, and whenever there is a gain of mechanical energy in an engine there is a loss of heat; and since the quantity of energy lost or gained is proportional to the quantity of heat gained or lost, we conclude that heat is a form of energy.

We have also reasons for believing that the minute particles of a hot body are in a state of rapid agitation, that is to say, that each particle is always moving very swiftly, but that the direction of its motion alters so often that it makes little or no progress from one region to another.

If this be the case, a part, and it may be a very large part, of the energy of a hot body must be in the form of kinetic energy.

But for our present purpose it is unnecessary to ascertain in what form energy exists in a hot body; the most important fact is that energy may be measured in the form of heat, and since every kind of energy may be converted into heat, this gives us one of the most convenient methods of measuring it.

Energy Measured as Heat.—Thus when certain substances are placed in contact chemical actions take place, the substances combine in a new way, and the new group of substances has different chemical properties from the original group of substances. During this process mechanical work may be done by the expansion of the mixture, as when gunpowder is fired; an electric current may be produced, as in the voltaic battery; and heat may be generated, as in most chemical actions.

The energy given out in the form of mechanical work may be measured directly, or it may be transformed into heat by friction. The energy spent in producing the electric current may be estimated as heat by causing the current to flow through a conductor of such a form that the heat generated in it can easily be measured. Care must be taken that no energy is transmitted to a distance in the form of sound or radiant heat without being duly accounted for.

The energy remaining in the mixture, together with the energy which has escaped, must be equal to the original energy.

Andrews, Favre and Silbermann, and others, have measured the quantity of heat produced when a certain quantity of oxygen or of chlorine combines with its equivalent of other substances. These measurements enable us to calculate the excess of the energy which the substances concerned had in their original state, when uncombined, above that which they have after combination.

Scientific Work to be done.—Though a great deal of excellent work of this kind has already been done, the extent of the field hitherto investigated appears quite insignificant when we consider the boundless variety and complexity of the natural bodies with which we have to deal.

In fact the special work which lies before the physical inquirer, in the present state of science, is the determination of the quantity of energy which enters or leaves a material system during the passage of the system from its standard state to any other definite state.

History of the Doctrine of Energy.—The scientific importance of giving a name to the quantity which we call kinetic energy seems to have been first recognized by Leibnitz, who gave to the product of the mass by the square of the velocity the name of *Vis Viva*. This is twice the kinetic energy.

Newton, in the "Scholium to the Laws of Motion," expresses the relation between the rate at which work is done by the external agent, and the rate at which it is given out, stored up, or transformed by any machine or other material system, in the following state-

ment, which he makes in order to show the wide extent of the application of the Third Law of Motion.

"If the action of the external agent is estimated by the product of its force into its velocity, and the reaction of the resistance in the same way by the product of the velocity of each part of the system into the resisting force arising from friction, cohesion, weight, and acceleration, the action and reaction will be equal to each other, whatever be the nature and motion of the system." That this statement of Newton's implicitly contains nearly the whole doctrine of energy was first pointed out by Thomson and Tait.

The words Action and Reaction as they occur in the enunciation of the Third Law of Motion are explained to mean Forces, that is to say, they are the opposite aspects of one and the same Stress.

In the passage quoted above a new and different sense is given to these words by estimating Action and Reaction by the product of a force into the velocity of its point of application. According to this definition the Action of the external agent is the rate at which it does work. This is what is meant by the Power of a steam-engine or other prime mover. It is generally expressed by the estimated number of ideal horses which would be required to do the work at the same rate as the engine, and this is called the Horse-power of the engine.

When we wish to express by a single word the rate at which work is done by an agent we shall call it the Power of the agent, defining the power as the work done in the unit of time.

The use of the term Energy, in a precise and scientific sense, to express the quantity of work which a material system can do, was introduced by Dr. Young.*

ON THE DIFFERENT FORMS OF ENERGY.—The energy which a body has in virtue of its motion is called kinetic energy.

A system may also have energy in virtue of its configuration, if the forces of the system are such that the system will do work against external resistance while it passes into another configuration. This energy is called Potential Energy. Thus when a stone has been lifted to a certain height above the earth's surface, the system of two bodies, the stone and the earth, has potential energy, and is able to do a certain amount of work during the descent of the stone. This potential energy is due to the fact that the stone and the earth attract each other, so that work has to be spent by the man who lifts the stone and draws it away from the earth, and after the stone is lifted the attraction between the earth and the stone is capable of doing work as the stone descends. This kind of energy, therefore, depends upon the work which the forces of the system would do if the parts of the system were to yield to the action of these forces. This is called the "Sum of the Tensions" by Helmholtz in his celebrated memoir on the "Conservation of Energy."* Thomson called it Statical Energy; it has also been called Energy of Position; but Rankine introduced the term Potential Energy—a very felicitous expression, since it not only signifies the energy which the system has not in actual possession, but only has the power to acquire, but it also indicates its connection with what has been called (on other grounds) the Potential Function.

The different forms in which energy has been found to exist in material systems have been placed in one or other of these two classes—Kinetic Energy, due to motion, and Potential Energy, due to configuration.

Thus a hot body, by giving out heat to a colder body, may be made to do work by causing the cold body to expand in opposition to pressure. A material system, therefore, in which there is a non-uniform distribution of temperature has the capacity of doing work, or energy. This energy is now believed to be kinetic energy, due to a motion of agitation in the smallest parts of the hot body.

Gunpowder has energy, for when fired it is capable of setting a cannon-ball in motion. The energy of gunpowder is Chemical Energy, arising from the power which the constituents of gunpowder possess of arranging themselves in a new manner when exploded, so as

* "Lectures on Natural Philosophy," Lecture VIII.

* Berlin, 1847. Translated in Taylor's "Scientific Memoirs," Feb. 1853.

to occupy a much larger volume than the gunpowder does. In the present state of science chemists figure to themselves chemical action as a rearrangement of particles under the action of forces tending to produce this change of arrangement. From this point of view, therefore, chemical energy is potential energy.

Air, compressed in the chamber of an air-gun, is capable of propelling a bullet. The energy of compressed air was at one time supposed to arise from the mutual repulsion of its particles. If this explanation were the true one its energy would be potential energy. In more recent times it has been thought that the particles of the air are in a state of motion, and that its pressure is caused by the impact of these particles on the sides of the vessel. According to this theory the energy of compressed air is kinetic energy.

There are thus many different modes in which a material system may possess energy, and it may be doubtful in some cases whether the energy is of the kinetic or the potential form. The nature of energy, however, is the same in whatever form it may be found. The quantity of energy can always be expressed as that of a body of a definite mass moving with a definite velocity.

CHAPTER VI.

RECAPITULATION.

Retrospect of Abstract Dynamics.—We have now gone through the part of the fundamental science of the motion of matter, which we have been able to treat in a manner sufficiently elementary to be consistent with the plan of this book.

It remains for us to take a general view of the relations between the parts of this science, and of the whole to other physical sciences, and this we can now do in a more satisfactory way than we could before we had entered into the subject.

Kinematics.—We began with kinematics, or the science of pure motion. In this division of the subject the ideas brought before us are those of space and time. The only attribute of matter which comes before us is its continuity of existence in space and time—the fact, namely, that every particle of matter, at any instant of time, is in one place and in one only, and that its change of place during any interval of time is accomplished by moving along a continuous path.

Neither the force which affects the motion of the body, nor the mass of the body, on which the amount of force required to produce the motion depends, comes under our notice in the pure science of motion.

Force.—In the next division of the subject force is considered in the aspect of that which alters the motion of a mass.

If we confine our attention to a single body, our investigation enables us, from observation of its motion, to determine the direction and magnitude of the resultant force which acts on it, and this investigation is the exemplar and type of all researches undertaken for the purpose of the discovery and measurement of physical forces.

But this may be regarded as a mere application of the definition of a force, and not as a new physical truth.

It is when we come to define equal forces as those which produce equal rates of acceleration in the same mass, and equal masses are those which are equally accelerated by equal forces, that we find that these definitions of equality amount to the assertion of the physical truth, that the comparison of quantities of matter by the forces required to produce in them a given acceleration is a method which always leads to consistent results, whatever be the absolute values of the forces and the accelerations.

Stress.—The next step in the science of force is that in which we pass from the consideration of a force as acting on a body, to that of its being one aspect of that mutual action between two bodies, which is called by Newton Action and Reaction, and which is now more briefly expressed by the single word Stress.

Relativity of Dynamical Knowledge.—Our whole progress up to this point may be described as a gradual development of the doctrine of relativity

of all physical phenomena. Position we must evidently acknowledge to be relative, for we cannot describe the position of a body in any terms which do not express relation. The ordinary language about motion and rest does not so completely exclude the notion of their being measured absolutely, but the reason of this is, that in our ordinary language we tacitly assume that the earth is at rest.

As our ideas of space and motion become clearer, we come to see how the whole body of dynamical doctrine hangs together in one consistent system.

Our primitive notion may have been that to know absolutely where we are, and in what direction we are going, are essential elements of our knowledge as conscious beings.

But this notion, though undoubtedly held by many wise men in ancient times, has been gradually dispelled from the minds of students of physics.

There are no landmarks in space; one portion of space is exactly like every other portion, so that we cannot tell where we are. We are, as it were, on an unruffled sea, without stars, compass, soundings, wind, or tide, and we cannot tell in what direction we are going. We have no log which we can cast out to take a dead reckoning by; we may compute our rate of motion with respect to the neighboring bodies, but we do not know how these bodies may be moving in space.

Relativity of Force.—We cannot even tell what force may be acting on us; we can only tell the difference between the force acting on one thing and that acting on another.

We have an actual example of this in our every-day experience. The earth moves round the sun in a year at a distance of 91,520,000 miles, or 1.473×10^{13} centimeters. It follows from this that a force is exerted on the earth in the direction of the sun, which produces an acceleration of the earth in the direction of the sun of about 0.019 in feet and seconds, or about $\frac{1}{1650}$ of the intensity of gravity at the earth's surface.

A force equal to the sixteen-hundredth part of the weight of a body might be easily measured by known experimental methods, especially if the direction of this force were differently inclined to the vertical at different hours of the day.

Now, if the attraction of the sun were exerted upon the solid part of the earth, as distinguished from the movable bodies on which we experiment, a body suspended by a string, and moving with the earth, would indicate the difference between the solar action on the body, and that on the earth as a whole.

If, for example, the sun attracted the earth and not the suspended body, then at sunrise the point of suspension, which is rigidly connected with the earth, would be drawn towards the sun, while the suspended body would be acted on only by the earth's attraction, and the string would appear to be deflected away from the sun by a sixteen-hundredth part of the length of the string. At sunset the string would be deflected away from the setting sun by an equal amount; and as the sun sets at a different point of the compass from that at which he rises the deflections of the string would be in different directions, and the difference in the position of the plumb-line at sunrise and sunset would be easily observed.

But instead of this, the attraction of gravitation is exerted upon all kinds of matter equally at the same distance from the attracting body. At sunrise and sunset the center of the earth and the suspended body are nearly at the same distance from the sun, and no deflection of the plumb-line due to the sun's attraction can be observed at these times. The attraction of the sun, therefore, in so far as it is exerted equally upon all bodies on the earth, produces no effect on their relative motions. It is only the differences of the intensity and direction of the attraction acting on different parts of the earth which can produce any effect, and these differences are so small for bodies at moderate distances that it is only when the body acted on is very large, as in the case of the ocean, that their effect becomes perceptible in the form of tides.

Rotation.—In what we have hitherto said about the motion of bodies, we have tacitly assumed that, in comparing one configuration of the system with another, we are able to draw a line in the final configuration parallel to a line in

the original configuration. In other words, we assume that there are certain directions in space which may be regarded as constant, and to which other directions may be referred during the motion of the system.

In astronomy, a line drawn from the earth to a star may be considered as fixed in direction, because the relative motion of the earth and the star is in general so small compared with the distance between them that the change of direction, even in a century, is very small. But it is manifest that all such directions of reference must be indicated by the configuration of a material system existing in space, and that if this system were altogether removed, the original directions of reference could never be recovered.

But, though it is impossible to determine the absolute velocity of a body in space, it is possible to determine whether the direction of a line in a material system is constant or variable.

For instance, it is possible by observations made on the earth alone, without reference to the heavenly bodies, to determine whether the earth is rotating or not.

So far as regards the geometrical configuration of the earth and the heavenly bodies, it is evidently all the same

> "Whether the sun, predominant in heaven,
> Rise on the earth, or earth rise on the sun;
> He from the east his flaming road begin,
> Or she from west her silent course advance
> With inoffensive pace that spinning sleeps
> On her soft axle, while she paces even,
> And bears thee soft with the smooth air along."

The distances between the bodies composing the universe, whether celestial or terrestrial, and the angles between the lines joining them, are all that can be ascertained without an appeal to dynamical principles, and these will not be affected if any motion of rotation of the whole system, similar to that of a rigid body about an axis, is combined with the actual motion; so that from a geometrical point of view the Copernican system, according to which the earth rotates, has no advantage, except that of simplicity, over that in which the earth is supposed to be at rest, and the apparent motions of the heavenly bodies to be their absolute motions.

Even if we go a step further, and consider the dynamical theory of the earth rotating round its axis, we may account for its oblate figure, and for the equilibrium of the ocean and of all other bodies on its surface on either of two hypothesis—that of the motion of the earth round its axis, or that of the earth not rotating, but caused to assume its oblate figure by a force acting outwards in all directions from its axis, the intensity of this force increasing as the distance from the axis increases. Such a force, if it acted on all kinds of matter alike, would account not only for the oblateness of the earth's figure, but for the conditions of equilibrium of all bodies at rest with respect to the earth.

It is only when we go further still, and consider the phenomena of bodies which are in motion with respect to the earth, that we are really constrained to admit that the earth rotates.

NEWTON'S DETERMINATION OF THE ABSOLUTE VELOCITY OF ROTATION.—Newton was the first to point out that the absolute motion of rotation of the earth might be demonstrated by experiments on the rotation of a material system. For instance, if a bucket of water is suspended from a beam by a string, and the string twisted so as to keep the bucket spinning round a vertical axis, the water will soon spin round at the same rate as the bucket, so that the system of the water and the bucket turns round its axis like a solid body.

The water in the spinning bucket rises up at the sides and is depressed in the middle, showing that in order to make it move in a circle a pressure must be exerted towards the axis. This concavity of the surface depends on the absolute motion of rotation of the water and not on its relative rotation.

For instance, it does not depend on the rotation relative to the bucket. For at the beginning of the experiment, when we set the bucket spinning, and before the water has taken up the motion, the water and the bucket are in relative motion, but the surface of the water is flat, because the water is not rotating, but only the bucket.

When the water and the bucket rotate together, there is no motion of the one relative to the other, but the surface of the water is hollow, because it is rotating.

When the bucket is stopped, as long

as the water continues to rotate its surface remains hollow, showing that it is still rotating though the bucket is not.

It is manifestly the same, as regards this experiment, whether the rotation be in the direction of the hands of a watch or the opposite direction, provided the rate of rotation is the same.

Now let us suppose this experiment tried at the North Pole. Let the bucket be made, by a proper arrangement of clockwork, to rotate either in the direction of the hands of a watch, or in the opposite direction, at a perfectly regular rate.

If it is made to turn round by clockwork once in twenty-four hours (sidereal time) the way of the hands of a watch laid face upwards, it will be rotating as regards the earth, but not rotating as regards the stars.

If the clockwork is stopped, it will rotate with respect to the stars, but not with respect to the earth.

Finally, if it is made to turn round once in twenty-four hours (sidereal time) in the opposite direction, it will be rotating with respect to the earth at the same rate as at first, but instead of being free from rotation as respects the stars, it will be rotating at the rate of one turn in twelve hours.

Hence if the earth is at rest, and the stars moving round it, the form of the surface will be the same in the first and last case; but if the earth is rotating, the water will be rotating in the last case but not in the first, and this will be made manifest by the water rising higher at the sides in the last case than in the first.

The surface of the water will not be really concave in any of the cases supposed, for the effect of gravity acting towards the center of the earth is to make the surface convex, as the surface of the sea is, and the rate of rotation in our experiment is not sufficiently rapid to make the surface concave. It will only make it slightly less convex than the surface of the sea in the last case, and slightly more convex in the first.

But the difference in the form of the surface of the water would be so exceedingly small, that with our methods of measurement it would be hopeless to attempt to determine the rotation of the earth in this way.

FOUCAULT'S PENDULUM.—The most satisfactory method of making an experiment for this purpose is that devised by M. Foucault.

A heavy ball is hung from a fixed point by a wire, so that it is capable of swinging like a pendulum in any vertical plane passing through the fixed point.

In starting the pendulum care must be taken that the wire, when at the lowest point of the swing, passes exactly through the position it assumes when hanging vertically. If it passes on one side of this position, it will return on the other side, and this motion of the pendulum round the vertical instead of through the vertical must be carefully avoided, because we wish to get rid of all motions of rotation either in one direction or the other.

Let us consider the angular momentum of the pendulum about the vertical line through the fixed point.

At the instant at which the wire of the pendulum passes through the vertical line, the angular momentum about the vertical line is zero.

The force of gravity always acts parallel to this vertical line, so that it cannot produce angular momentum round it. The tension of the wire always acts through the fixed point, so that it cannot produce angular momentum about the vertical line.

Hence the pendulum can never acquire angular momentum about the vertical line through the point of suspension.

Hence when the wire is out of the vertical, the vertical plane through the center of the ball and the point of suspension cannot be rotating; for if it were, the pendulum would have an angular momentum about the vertical line.

Now let us suppose this experiment performed at the North Pole. The plane of vibration of the pendulum will remain absolutely constant in direction, so that if the earth rotates the rotation of the earth will be made manifest.

We have only to draw a line on the earth parallel to the plane of vibration, and to compare the position of this line with that of the plane of vibration at a subsequent time.

As a pendulum of this kind properly suspended will swing for several hours, it is easy to ascertain whether the posi-

sition of the plane of vibration is constant as regards the earth, as it would be if the earth is at rest, or constant as regards the stars, if the stars do not move round the earth.

We have supposed, for the sake of simplicity in the description, that the experiment is made at the North Pole. It is not necessary to go there in order to demonstrate the rotation of the earth. The only region where the experiment will not show it is at the equator.

At every other place the pendulum will indicate the rate of rotation of the earth with respect to the vertical line at that place. If at any instant the plane of the pendulum passes through a star near the horizon either rising or setting, it will continue to pass through that star as long as it is near the horizon. That is to say, the horizontal part of the apparent motion of a star on the horizon is equal to the rate of rotation of the plane of vibration of the pendulum.

It has been observed that the plane of vibration appears to rotate in the opposite direction in the southern hemisphere, and by a comparison of the rates at various places the actual time of rotation of the earth has been deduced without reference to astronomical observations. The mean value, as deduced from these experiments by Messrs. Galbraith and Houghton in their "Manual of Astronomy," is $23^{h.}\ 53^{m.}\ 3\frac{1}{2}^{s.}$. The true time of rotation of the earth is $23^{h.}\ 56^{m}\ 4^{s.}$ mean solar time.

MATTER AND ENERGY.—All that we know about matter relates to the series of phenomena in which energy is transferred from one portion of matter to another, till in some part of the series our bodies are affected, and we become conscious of a sensation.

By the mental process which is founded on such sensations we come to learn the conditions of these sensations, and to trace them to objects which are not part of ourselves, but in every case the fact that we learn is the mutual action between bodies. This mutual action we have endeavored to describe in this treatise. Under various aspects it is called Force, Action and Reaction, and Stress, and the evidence of it is the change of the motion of the bodies between which it acts.

The process by which stress produces change of motion is called Work, and, as we have already shown, work may be considered as the transference of Energy from one body or system to another.

Hence, as we have said, we are acquainted with matter only as that which may have energy communicated to it from other matter, and which may, in its turn, communicate energy to other matter.

Energy, on the other hand, we know only as that which in all natural phenomena is continually passing from one portion of matter to another.

TEST OF A MATERIAL SUBSTANCE.—Energy cannot exist except in connection with matter. Hence since, in the space between the sun and the earth, the luminous and thermal radiations, which have left the sun and which have not reached the earth, possess energy, the amount of which per cubic mile can be measured; this energy must belong to matter existing in the interplanetary spaces, and since it is only by the light which reaches us that we become aware of the existence of the most remote stars, we conclude that the matter which transmits light is disseminated through the whole of the visible universe.

ENERGY NOT CAPABLE OF IDENTIFICATION.—We cannot identify a particular portion of energy, or trace it through its transformations. It has no individual existence, such as that which we attribute to particular portions of matter.

The transactions of the material universe appear to be conducted, as it were, on a system of credit. Each transaction consists of the transfer of so much credit or energy from one body to another. This act of transfer or payment is called work. The energy so transferred does not retain any character by which it can be identified when it passes from one form to another.

ABSOLUTE VALUE OF THE ENERGY OF A BODY UNKNOWN.—The energy of a material system can only be estimated in a relative manner.

In the first place, though the energy of the motion of the parts relative to the center of mass of the system may be accurately defined, the whole energy con-

sists of this together with the energy of a mass equal to that of the whole system moving with the velocity of the center of mass. Now this latter velocity—that of the center of mass—can be estimated only with reference to some body external to the system, and the value which we assign to this velocity will be different according to the body which we select as our origin.

Hence the estimated kinetic energy of a material system contains a part, the value of which cannot be determined except by the arbitrary selection of an origin. The only origin which would not be arbitrary is the center of mass of the material universe, but this is a point the position and motion of which are quite unknown to us.

Latent Energy.—But the energy of a material system is indeterminate for another reason. We cannot reduce the system to a state in which it has no energy, and any energy which is never removed from the system must remain unperceived by us, for it is only as it enters or leaves the system that we can take any account of it.

We must, therefore, regard the energy of a material system as a quantity of which we may ascertain the increase or diminution as the system passes from one definite condition to another. The absolute value of the energy in the standard condition is unknown to us, and it would be of no value to us if we did know it, as all phenomena depend on the variations of the energy, and not on its absolute value.

A Complete Discussion of Energy would include the whole of Physical Science.—The discussion of the various forms of energy—gravitational, electromagnetic, molecular, thermal, &c.—with the conditions of the transference of energy from one form to another, and the constant dissipation of the energy available for producing work, constitutes the whole of physical science, in so far as it has been developed in the dynamical form under the various designations of Astronomy, Electricity, Magnetism, Optics, Theory of the Physical States of Bodies, Thermo-dynamics, and Chemistry.

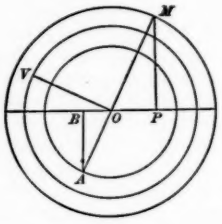
CHAPTER VII.

THE PENDULUM AND GRAVITY.

On Uniform Motion in a Circle.—Let M (Fig. 11) be a body moving in a circle with velocity V.

Let $\overline{O\,M}=r$ be the radius of the circle.

Fig. 11.



The direction of the velocity of M is that of the tangent to the circle. Draw $\overline{O\,V}$ parallel to this direction through the center of the circle and equal to the distance described in unit of time with velocity V, then $\overline{O\,V}=V$.

If we take O as the origin of the diagram of velocity, V will represent the velocity of the body at M.

As the body moves round the circle, the point V will also describe a circle, and the velocity of the point V will be to that of M as $\overline{O\,V}$ to $\overline{O\,M}$.

If, therefore, we draw $\overline{O\,A}$ in $\overline{M\,O}$ produced, and therefore parallel to the direction of motion of V, and make $\overline{O\,A}$ a third proportional to $\overline{O\,M}$ and $\overline{O\,V}$, and if we assume O as the origin of the diagram of rate of acceleration, then the point A will represent the velocity of the point V, or, what is the same thing, the rate of acceleration of the point M.

Hence, when a body moves with uniform velocity in a circle, its acceleration is directed towards the center of the circle, and is a third proportional to the radius of the circle and the velocity of the body.

The force acting on the body M is equal to the product of this acceleration into the mass of the body, or if F be this force

$$F=\frac{MV^2}{r}$$

Centrifugal Force.—This is the force which must act on the body M in

order to keep it in the circle of radius v, in which it is moving with velocity V.

The direction of this force is towards the center of the circle.

If this force is applied by means of a string fastened to the body, the string will be in a state of tension. To a person holding the other end of the string this tension will appear to be directed towards the body M, as if the body M had a tendency to move away from the center of the circle which it is describing.

Hence this latter force is often called Centrifugal Force.

The force which really acts on the body, being directed towards the center of the circle, is called Centripetal Force, and in some popular treatises the centripetal and centrifugal forces are described as opposing and balancing each other. But they are merely the different aspects of the same stress.

Periodic Time.—The time of describing the circumference of the circle is called the Periodic Time. If π represents the ratio of the circumference of a circle to its diameter, which is 3.14159 . . . . . the circumference of a circle of radius r is $2\pi r$, and since this is described in the periodic time T with velocity V, we have

$$2\pi r = V T$$

Hence $$F = 4\pi^2 M \frac{r}{T^2}$$

The rate of circular motion is often expressed by the number of revolutions in unit of time. Let this number be denoted by n, then

$$n T = 1$$

and $$F = 4\pi^2 M r n^2.$$

On Simple Harmonic Vibrations.—If while the body M (Fig. 11) moves in a circle with uniform velocity another point P moves in a fixed diameter of the circle, so as to be always at the foot of the perpendicular from M on that diameter, the body P is said to execute Simple Harmonic Vibrations.

The radius, r, of the circle is called the Amplitude of the vibration.

The periodic time of M is called the Periodic Time of Vibration.

The angle which O M makes with the positive direction of the fixed diameter is called the Phase of the vibration.

On the Force Acting on the Vibrating Body.—The only difference between the motions of M and P is that M has a vertical motion compounded with a horizontal motion which is the same as that of P. Hence the velocity and the acceleration of the two bodies differ only with respect to the vertical part of the velocity and acceleration of M.

The acceleration of P is therefore the horizontal component of that of M, and since the acceleration of M is represented by O A, which is in the direction of M O produced, the acceleration of P will be represented by O B, where B is the foot of the perpendicular from A on the horizontal diameter. Now by similar triangles O M P, O A B

$$O M : O A :: O P : O B$$

But $O M = r$ and $O A = -4\pi^2 \frac{r}{T^2}$. Hence

$$O B = -\frac{4\pi^2}{T^2} O P = -4\pi^2 n^2 O P$$

In simple harmonic vibration, therefore, the acceleration is always directed towards the center of vibration, and is equal to the distance from that center multiplied by $4\pi^2 n^2$, and if the mass of the vibrating body is P, the force acting on it at a distance x from O is $4\pi^2 n^2 P x$.

It appears, therefore, that a body which executes simple harmonic vibrations in a straight line is acted on by a force which varies as the distance from the center of vibration, and the value of this force at a given distance depends only on that distance, on the mass of the body, and on the square of the number of vibrations in unit of time, and is independent of the amplitude of the vibrations.

Isochronous Vibrations.—It follows from this that if a body moves in a straight line and is acted on by a force directed towards a fixed point on the line and varying as the distance from that point, it will execute simple harmonic vibrations, the periodic time of which will be the same whatever the amplitude of vibration.

If, for a particular kind of displace-

ment of a body, as turning round an axis, the force tending to bring it back to a given position varies as the displacement, the body will execute simple harmonic vibrations about that position, the periodic time of which will be independent of their amplitude.

Vibrations of this kind, which are executed in the same time whatever be their amplitude, are called Isochronous Vibrations.

Potential Energy of the Vibrating Body.—The velocity of the body when it passes through the point of equilibrium is equal to that of the body moving in the circle, or $V=2\pi\, r\, n$,
where r is the amplitude of vibration and n is the number of double vibrations per second.

Hence the kinetic energy of the vibrating body at the point of equilibrium is

$$\tfrac{1}{2}\, M\, V^2=2\pi^2\, M r^2\, n^2$$

where M is the mass of the body.

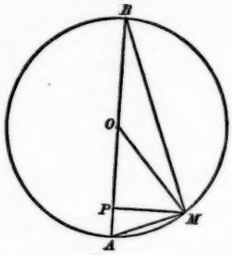
At the extreme elongation, where $x=r$, the velocity, and therefore the kinetic energy, of the body is zero. The diminution of kinetic energy must correspond to an equal increase of potential energy. Hence if we reckon the potential energy from the configuration in which the body is at its point of equilibrium, its potential energy when at a distance, r, from this point is $2\pi^2 M\, n^2\, r^2$.

This is the potential energy of a body which vibrates isochronously, and executes n double variations per second when it is at rest at the distance, r, from the point of equilibrium. As the potential energy does not depend on the motion of the body, but only on its position, we may write it $2\pi^2 M\, n^2\, x^2$,

where x is the distance from the point of equilibrium.

The Simple Pendulum.—The simple pendulum consists of a small heavy body called the bob, suspended from a fixed point by a fine string of invariable length. The bob is supposed to be so small that its motion may be treated as that of a material particle, and the string is supposed to be so fine that we may neglect its mass and weight. The bob is set in motion so as to swing through a small angle in a vertical plane. Its path, therefore, is an arc of a circle, whose center is the point of suspension, O, and whose radius is the length of the string, which we shall denote by l.

Fig. 12.



Let O (Fig. 12) be the point of suspension and O A the position of the pendulum when hanging vertically. When the bob is at M it is higher than when it is at A by the height $AP=\frac{\overline{AM}^2}{\overline{AB}}$
where AM is the chord of the arc ALM and $AB=2l$.

If M be the mass of the bob and g the intensity of gravity the weight of the bob will be Mg and the work done against gravity during the motion of the bob from A to M will be $Mg\ \overline{AP}$. This, therefore, is the potential energy of the pendulum when the bob is at M, reckoning the energy zero when the bob is at A.

We may write this energy

$$\frac{Mg}{2l}\,\overline{AM}^2$$

The potential energy of the bob when displaced through any arc varies as the square of the chord of that arc.

If it had varied as the square of the arc itself in which the bob moves, the vibrations would have been strictly isochronous. As the potential energy varies more slowly than the square of the arc, the period of each vibration will be greater when the amplitude is greater.

For very small vibrations, however, we may neglect the difference between the chord and the arc, and denoting the arc by x we may write the potential energy

$$\frac{Mg}{2l}x^2$$

But we have already shown that in har-

monic vibrations the potential energy is $2\pi^2 M n^2 x^2$.

Equating these two expressions and clearing fractions we find

$$g = 4\pi^2 n^2 l,$$

where g is the intensity of gravity, π is the ratio of the circumference of a circle to its diameter, n is the number of vibrations of the pendulum in unit of time, and l is the length of the pendulum.

A Rigid Pendulum.—If we could construct a pendulum with a bob so small and a string so fine that it might be regarded for practical purposes as a simple pendulum, it would be easy to determine g by this method. But all real pendulums have bobs of considerable size, and in order to preserve the length invariable the bob must be connected with the point of suspension by a stout rod, the mass of which cannot be neglected. It is always possible, however, to determine the length of a simple pendulum whose vibrations would be executed in the same manner as those of a pendulum of any shape.

The complete discussion of this subject would lead us into calculations beyond the limits of this treatise. We may, however, arrive at the most important result without calculation as follows:

The motion of a rigid body in one plane may be completely defined by stating the motion of its center of mass, and the motion of the body round its center of mass.

The force required to produce a given change in the motion of the center of mass depends only on the mass of the body. "Effect of External Forces on the Motion of the Center of Mass."

The moment required to produce a given change of angular velocity about the center of mass depends on the distribution of the mass, being greater the further the different parts of the body are from the center of mass.

If, therefore, we form a system of two particles rigidly connected, the sum of the masses being equal to the mass of a pendulum, their center of mass coinciding with that of the pendulum, and their distances from the center of mass being such that a couple of the same moment is required to produce a given rotatory motion about the center of mass of the new system as about that of the pendulum, then the new system will for motions in a center plane be dynamically equivalent to the given pendulum, that is, if the two systems are moved in the same way the forces required to guide the motion will be equal. Since the two particles may have any ratio, provided the sum of their masses is equal to the mass of the pendulum, and since the line joining them may have any direction provided it passes through the center of mass, we may arrange them so that one of the particles corresponds to any given point of the pendulum, say, the point of suspension P (Fig. 13). The mass of

Fig. 13.

this particle and the position and mass of the other at Q will be determinate. The position of the second particle, Q, is called the Center of Oscillation. Now in the system of two particles, if one of them, P, is fixed, and the other, Q, allowed to swing under the action of gravity, we have a simple pendulum. For one of the particles, P, acts as the point of suspension, and the other, Q, is at an invariable distance from it, so that the connection between them is the same as if they were united by a string of length $l = \overline{PQ}$.

Hence a pendulum of any form swings in exactly the same manner as a simple pendulum whose length is the distance from the center of suspension to the center of oscillation.

Inversion of the Pendulum.—Now let us suppose the system of two particles inverted, Q being made the point of suspension and P being made to swing. We have now a simple pendulum of the same length as before. Its vibrations will therefore be executed in the same time. But it is dynamically equivalent to the pendulum suspended by its center of oscillation.

Hence if a pendulum be inverted and suspended by its center of oscillation its vibrations will have the same period as before, and the distance between the center of suspension and that of oscilla-

tion will be equal to that of a simple pendulum having the same time of vibration.

It was in this way that Captain Kater determined the length of the simple pendulum which vibrates seconds.

He constructed a pendulum which could be made to vibrate about two knife edges, on opposite sides of the center of mass and at *unequal* distances from it.

By certain adjustments, he made the time of vibration the same whether the one knife edge or the other were the center of suspension. The length of the corresponding simple pendulum was then found by measuring the distance between the knife edges.

ILLUSTRATION OF KATER'S PENDULUM.—The principle of Kater's Pendulum may be illustrated by a very simple and striking experiment. Take a flat board of any form (Fig. 14), and drive a piece

FIG. 14.

of wire through it near its edge, and allow it to hang in a vertical plane, holding the ends of the wire by the finger and thumb. Take a small bullet, fasten it to the end of a thread and allow the thread to pass over the wire, so that the bullet hangs close to the board. Move the hand by which you hold the wire horizontally in the plane of the board, and observe whether the board moves forwards or backwards with respect to the bullet. If it moves forwards lengthen the string, if backwards shorten it till the bullet and the board move together. Now mark the point of the board opposite the center of the bullet and fasten the string to the wire. You will find that if you hold the wire by the ends and move it in any manner, however sudden and irregular, in the plane of the board, the bullet will never quit the marked spot on the board.

Hence this spot is called the center of oscillation, because when the board is oscillating about the wire when fixed it oscillates as if it consisted of a single particle placed at the spot.

It is also called the center of percussion, because if the board is at rest and the wire is suddenly moved horizontally the board will at first begin to rotate about the spot as a center.

DETERMINATION OF THE INTENSITY OF GRAVITY.—The most direct method of determining g is, no doubt, to let a body fall and find what velocity it has gained in a second, but it is very difficult to make accurate observations of the motion of bodies when their velocities are so great as 981 centimeters per second, and besides, the experiment would have to be conducted in a vessel from which the air has been exhausted, as the resistance of the air to such rapid motion is very considerable, compared with the weight of the falling body.

The experiment with the pendulum is much more satisfactory. By making the arc of vibration very small, the motion of the bob becomes so slow that the resistance of the air can have very little influence on the time of vibration. In the best experiments the pendulum is swung in an air-tight vessel from which the air is exhausted.

Besides this, the motion repeats itself, and the pendulum swings to and fro hundreds, or even thousands, of times before the various resistances to which it is exposed reduce the amplitude of the vibrations till they can no longer be observed.

Thus the actual observation consists not in watching the beginning and end of one vibration, but in determining the duration of a series of many hundred vibrations, and thence deducing the time of a single vibration.

The observer is relieved from the labor of counting the whole number of vibrations, and the measurement is made one of the most accurate in the whole range of practical science by the following method:

METHOD OF OBSERVATION.—A pendulum clock is placed behind the experimental pendulum, so that when both pendulums are hanging vertically the

bob, or some other part of the experimental pendulum, just hides a white spot on the clock pendulum, as seen by a telescope fixed at some distance in front of the clock.

Observations of the transit of "clock stars" across the meridian are made from time to time, and from these the rate of the clock is deduced in terms of "mean solar time."

The experimental pendulum is then set a swinging, and the two pendulums are observed through the telescope. Let us suppose that the time of a single vibration is not exactly that of the clock pendulum, but a little more.

The observer at the telescope sees the clock pendulum always gaining on the experimental pendulum, till at last the experimental pendulum just hides the white spot on the clock pendulum as it crosses the vertical line. The time at which this takes place is observed and recorded as the First Positive Coincidence.

The clock pendulum continues to gain on the other, and after a certain time the two pendulums cross the vertical line at the same instant in opposite directions. The time of this is recorded as the First Negative Coincidence. After an equal interval of time there will be a second positive coincidence, and so on.

By this method the clock itself counts the number, N, of vibrations of its own pendulum between the coincidences. During this time the experimental pendulum has executed one vibration less than the clock. Hence the time of vibration of the experimental pendulum is $\frac{N}{N-1}$ seconds of clock time.

When there is no exact coincidence, but when the clock pendulum is ahead of the experimental pendulum at one passage of the vertical and behind at the next, a little practice on the part of the observer will enable him to estimate at what time between the passages the two pendulums must have been in the same phase. The epoch of coincidence can thus be estimated to a fraction of a second.

Estimation of Error.—The experimental pendulum will go on swinging for some hours, so that the whole time to be measured may be ten thousand or more vibrations.

But the error introduced into the calculated time of vibration, by a mistake even of a whole second in noting the time of vibration, may be made exceedingly small by prolonging the experiment.

For if we observe the first and the nth coincidence, and find that they are separated by an interval of N seconds of the clock, the experimental pendulum will have lost n vibrations, as compared with the clock, and will have made $N-n$ vibrations in N seconds. Hence the time of a single vibration is $T=\frac{N}{N-n}$ seconds of clock time.

Let us suppose, however, that by a mistake of a second we note down the last coincidence as taking place $N+1$ seconds after the first. The value of T as deduced from this result would be

$$T'=\frac{N+1}{N+1-n}$$

and the error introduced by the mistake of a second will be

$$T'-T=\frac{N+1}{N+1-n}-\frac{N}{N-n}$$

$$=\frac{n}{(N+1-n)\ (N-n)}$$

If N is 10000 and n is 100, a mistake of one second in noting the time of coincidence will alter the value of T only about one-millionth part of its value.

CHAPTER VIII.

UNIVERSAL GRAVITATION.

Newton's Method.—The most instructive example of the method of dynamical reasoning is that by which Newton determined the law of the force with which the heavenly bodies act on each other.

The process of dynamical reasoning consists in deducing from the successive configurations of the heavenly bodies, as observed by astronomers, their velocities and their accelerations, and in this way determining the direction and the relative magnitude of the force which acts on them.

Kepler had already prepared the way for Newton's investigation, by deducing

from a careful study of the observations of Tycho Brahe the three laws of planetary motion which bear his name.

KEPLER'S LAWS.—Kepler's Laws are purely kinematical. They completely describe the motions of the planets, but they say nothing about the forces by which these motions are determined.

Their dynamical interpretation was discovered by Newton.

The first and second law relate to the motion of a single planet.

Law I.—The areas swept out by the vector drawn from the sun to a planet are proportional to the times of describing them. If h denotes twice the area swept out in unit of time, twice the area swept out in time t will be $h\,t$, and if P is the mass of the planet, $P\,h\,t$ will be the mass-area as defined in "Definition of a Mass-Area." Hence the angular momentum of the planet about the sun, which is the rate of change of the mass-area, will be $P\,h$, a constant quantity.

Hence, by "Moment of a Force about a Point," the force, if any, which acts on the planet must have no moment with respect to the sun, for if it had it would increase or diminish the angular momentum at a rate measured by the value of this moment.

Hence, whatever be the force which acts on the planet, the direction of this force must always pass through the sun.

ANGULAR VELOCITY.—Definition. The angular velocity of a vector is the rate at which the angle increases which it makes with a fixed vector in the plane of its motion.

If ω is the angular velocity of a vector, and r its length, the rate at which it sweeps out an area is $\frac{1}{2}\omega\, r^2$. Hence,

$$h = \omega\, r^2$$

and since h is constant, ω, the angular velocity of a planet's motion round the sun, varies inversely as the square of the distance from the sun.

This is true whatever the law of force may be, provided the force acting on the planet always passes through the sun.

MOTION ABOUT THE CENTER OF MASS.—Since the stress between the planet and the sun acts on both bodies, neither of them can remain at rest. The only point whose motion is not affected by the stress is the center of mass of the two bodies.

FIG. 15.

If r is the distance S P (Fig. 15), and if C is the center of mass, $\overline{SC} = \frac{Pr}{S+P}$ and $\overline{CP} = \frac{Sr}{S+P}$. The angular momentum of P about C is $P\omega\,\frac{S^2r^2}{(S+P)^2} = \frac{PS^2}{(S+P)^2}h$.

THE ORBIT.—We have already made use of diagrams of configuration and of velocity in studying the motion of a material system. These diagrams, however, represent only the state of the system at a given instant; and this state is indicated by the relative position of points corresponding to the bodies forming the system.

It is often, however, convenient to represent in a single diagram the whole series of configurations or velocities which the system assumes. If we suppose the points of the diagram to move so as continually to represent the state of the moving system, each point of the diagram will trace out a line, straight or curved.

On the diagram of configuration, this line is called, in general, the Path of the body. In the case of the heavenly bodies it is often called the Orbit.

THE HODOGRAPH.—On the diagram of velocity the line traced out by each moving point is called the Hodograph of the body to which it corresponds.

The study of the Hodograph, as a method of investigating the motion of a body, was introduced by Sir W. R. Hamilton. The hodograph may be defined as the path traced out by the extremity of a vector which continually represents, in direction and magnitude, the velocity of a moving body.

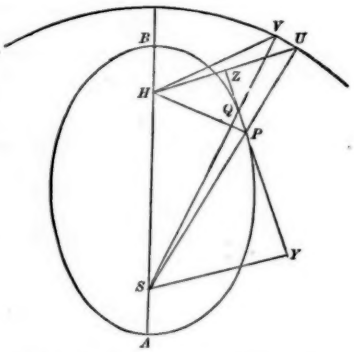
In applying the method of the hodograph to a planet, the orbit of which is

in one plane, we shall find it convenient to suppose the hodograph turned round its origin through a right angle, so that the vector of the hodograph is perpendicular instead of parallel to the velocity it represents.

KEPLER'S SECOND LAW.—LAW II.—The orbit of a planet with respect to the sun is an ellipse, the sun being in one of the foci.

Let A P Q B (Fig. 16) be the elliptic orbit. Let S be the sun in one focus, and let H be the other focus. Produce S P to U, so that S U is equal to the transverse axis A B, and join H U, then H U will be proportional and perpendicular to the velocity at P.

FIG. 16.



For bisect H U in Z and join Z P, Z P will be a tangent to the ellipse at P; let S Y be a perpendicular from S on this tangent.

If v is the velocity at P, and h twice the area swept out in unit of time $h = v\,\overline{SY}$.

Also if b is half the conjugate axis of the ellipse

$$\overline{SY} \cdot \overline{HZ} = b^2$$

Now HU = 2HZ; hence

$$v = \tfrac{1}{2}\frac{h}{b^2}\overline{HU}$$

Hence HU is always proportional to the velocity, and it is perpendicular to its direction. Now SU is always equal to AB. Hence the circle whose center is S and radius A B is the hodograph of the planet, H being the origin of the hodograph.

The corresponding points of the orbit and the hodograph are those which lie in the same straight line through S.

Thus P corresponds to U and Q to V.

The velocity communicated to the body during its passage from P to Q is represented by the geometrical difference between the vectors HU and HV, that is, by the line UV, and it is perpendicular to this arc of the circle, and is therefore, as we have already proved, directed towards S.

If P Q is the arc described in unit of time, then UV represents the acceleration, and since UV is on a circle whose center is S, UV will be a measure of the angular velocity of the planet about S. Hence the acceleration is proportional to the angular velocity, and this by "Angular Velocity" is inversely as the square of the distance SP. Hence the acceleration of the planet is in the direction of the sun, and is inversely as the square of the distance from the sun.

This, therefore, is the law according to which the attraction of the sun on a planet varies as the planet moves in its orbit and alters its distance from the sun.

FORCE ON A PLANET.—Since, as we have already shown, the orbit of the planet with respect to the center of mass of the sun and planet has its dimensions in the ratio of S to S+P to those of the orbit of the planet with respect to the Sun, if $2a$ and $2b$ are the axes of the orbit of the planet with respect to the sun, the area is $\pi\, a\, b$, and if T is the time of going completely round the orbit, the value of h is $2\pi\,\frac{ab}{T}$

The velocity with respect to the sun is, therefore,

$$\pi\,\frac{a}{T\,b}\overline{HU}$$

With respect to the center of mass it is

$$\frac{S}{S+P}\,\frac{\pi a}{Tb}\overline{HU}$$

The acceleration of the planet towards the center of mass is

$$\frac{S}{S+P}\,\frac{\pi a}{Tb}\,U\,V$$

and the impulse on that planet whose mass is P is therefore

$$\frac{S \cdot P}{S+P} \frac{\pi a}{T b} U V$$

Let t be the time of describing P Q, then twice the area S P Q is

$$h t = \omega r^2 t$$

and $$UV = 2a\ \omega t = 2a \frac{h}{r^2} t = 4\pi \frac{a^2 b}{T r^2} t.$$

Hence the force on the planet is

$$F = 4\pi^2 \frac{S \cdot P}{S+P} \frac{a^3}{T^2 r^2}$$

This then is the value of the stress or attraction between a planet and the sun in terms of their masses P and S, their mean distance a, their actual distance r, and the periodical time T.

INTERPRETATION OF KEPLER'S THIRD LAW.—To compare the attraction between the sun and different planets, Newton made use of Kepler's third law.

Law III.—The squares of the time of different planets are proportional to the cubes of their mean distances.

In other words $\frac{a^3}{T^2}$ is a constant, say $\frac{C}{4\pi^2}$

Hence $$F = C \frac{S.P}{S+P} \frac{1}{r^2}$$

In the case of the smaller planets their masses are so small, compared with that of the sun, that $\frac{S}{S+P}$ may be put equal to 1, so that $F = C\,P \frac{1}{r^2}$

or the attraction on a planet is proportional to its mass and inversely as the square of its distance.

LAW OF GRAVITATION.—This is the most remarkable fact about the attraction of gravitation, that at the same distance it acts equally on equal masses of substances of all kinds. This is proved by pendulum experiments for the different kinds of matter at the surface of the earth. Newton extended the law to the matter of which the different planets are composed.

It had been suggested, before Newton proved it, that the sun as a whole attracts a planet as a whole, and the law of the inverse square had also been previously stated, but in the hands of Newton the doctrine of gravitation assumed its final form.

Every portion of matter attracts every other portion of matter, and the stress between them is proportional to the product of their masses divided by the square of their distance.

For if the attraction between a gramme of matter in the sun and a gramme of matter in a planet at distance r is $\frac{C}{r^2}$ where C is a constant, then if there are S grammes in the sun and P in the planet the whole attraction between the sun and one gramme in the planet will be $\frac{CS}{r^2}$, and the whole attraction between the sun and the planet will be $C \frac{SP}{r^2}$.

Comparing this statement of Newton's "Law of Universal Gravitation" with the value of F formerly obtained we find

$$C \frac{S.P}{r^2} = 4\pi^2 \frac{S.P}{S+P} \frac{a^3}{T^2 r^2}$$

$$\text{or } 4\pi^2 a^3 = C(S+P)T^2.$$

AMENDED FORM OF KEPLER'S THIRD LAW.—Hence Kepler's Third Law must be amended thus:

The cubes of the mean distances are as the squares of the times multiplied into the sum of the masses of the sun and the planet.

In the case of the larger planets, Jupiter, Saturn, &c., the value of S+P is considerably greater than in the case of the earth and the smaller planets. Hence the periodic times of the larger planets should be somewhat less than they would be according to Kepler's law, and this is found to be the case.

In the following table the mean distances (a) of the planets are given in terms of the mean distance of the earth, and the periodic time T in terms of the sidereal year:

(*See Table on following page.*)

It appears from the table that Kepler's third law is very nearly accurate, for a^3 is very nearly equal to T^2, but that for those planets whose mass is less than that of the earth—namely, Mercury, Venus and Mars—a^3 is less than T^2, whereas for Jupiter, Saturn, Uranus and Neptune, whose mass is greater than that of the earth, a^3 is greater than T^2.

POTENTIAL ENERGY DUE TO GRAVITATION.—The potential energy of the gravi-

Planet.	a	T	a_3	T_2	a^3-T_2
Mercury..	0.387098	0.24084	0.0580046	0.0580049	− 0.0000003
Venus....	0.72333	0.61518	0.378451	0.378453	− 0.0000002
Earth.....	1.0000	1.00000	1.00000	1.00000	
Mars.....	1.52369	1.88082	3.53746	3.53747	− 0.00001
Jupiter....	5.20278	11.8618	140.832	140.701	+ 0.131
Saturn....	9.53879	29.4560	867.914	867.658	+ 0.256
Uranus...	19.1824	84.0123	7058.44	7058.07	+ 0.37
Neptune..	30.037	164.616	27100.0	27098.4	+ 1.6

tation between the bodies S and P may be calculated when we know the attraction between them in terms of their distance. The process of calculation by which we sum up the effects of a continually varying quantity belongs to the Integral Calculus, and though in this case the calculation may be explained by elementary methods, we shall rather deduce the potential energy directly from Kepler's first and second laws.

These laws completely define the motion of the sun and planet, and therefore we may find the kinetic energy of the system corresponding to any part of the elliptic orbit. Now, since the sun and planet form a conservative system, the sum of the kinetic and potential energy is constant, and therefore when we know the kinetic energy we may deduce that part of the potential energy which depends on the distance between the bodies.

KINETIC ENERGY OF THE SYSTEM.— To determine the kinetic energy we observe that the velocity of the planet with respect to the sun is by "Kepler's Second Law."

$$v=\tfrac{1}{2}\frac{h}{b^2}\overline{\mathrm{HU}}$$

The velocities of the planet and the sun with respect to the center of mass of the system are respectively

$$\frac{\mathrm{S}}{\mathrm{S}+\mathrm{P}}v \quad \text{and} \quad \frac{\mathrm{P}}{\mathrm{S}+\mathrm{P}}v$$

The kinetic energies of the planet and the sun are therefore

$$\tfrac{1}{2}\mathrm{P}\frac{\mathrm{S}^2v^2}{(\mathrm{S}+\mathrm{P})^2} \quad \text{and} \quad \tfrac{1}{2}\mathrm{S}\frac{\mathrm{P}^2}{(\mathrm{S}+\mathrm{P}^2)}v^2$$

and the whole kinetic energy is

$$\tfrac{1}{2}\frac{\mathrm{S}\,.\,\mathrm{P}}{\mathrm{S}+\mathrm{P}}v^2=\tfrac{1}{4}\frac{\mathrm{S}\,.\,\mathrm{P}}{\mathrm{S}+\mathrm{P}}\frac{h^2}{b^2}\overline{\mathrm{HU}^2}$$

To determine v^2 in terms of $\overline{\mathrm{SP}}$ or r, we observe that by the law of areas

$$v\,.\,\overline{\mathrm{SY}}=h=\frac{2\pi ab}{\mathrm{T}} \quad . \quad . \quad . \quad (1)$$

also by a property of the ellipse

$$\overline{\mathrm{HZ}}\,.\,\overline{\mathrm{SY}}=b^2 \quad . \quad . \quad . \quad . \quad (2)$$

and by the similar triangles HZP and SYP

$$\frac{\overline{\mathrm{SY}}}{\overline{\mathrm{HZ}}}=\frac{\overline{\mathrm{HP}}}{\overline{\mathrm{SP}}}=\frac{r}{2a-r} \quad . \quad . \quad (3)$$

multiplying (2) and (3) we find

$$\overline{\mathrm{SY}}^2=\frac{b^2r}{2a-r}$$

Hence by (1)

$$v^2=\frac{4\pi^2a^2b^2}{\mathrm{T}^2}\frac{1}{\overline{\mathrm{SY}}^2}=\frac{4\pi^2a^2}{\mathrm{T}^2}\left(\frac{2a}{r}-1\right)$$

and the kinetic energy of the system is

$$\frac{4\pi^2a^2}{\mathrm{T}^2}\frac{\mathrm{S}\,.\,\mathrm{P}}{\mathrm{S}+\mathrm{P}}\left(\frac{1}{r}-\frac{1}{2a}\right)$$

and this by the equation at the end of "Law of Gravitation" becomes

$$\mathrm{C}\,.\,\mathrm{S}\,.\,\mathrm{P}\left(\frac{1}{r}-\frac{1}{2a}\right)$$

where C is the constant of gravitation.

This is the value of the kinetic energy of the two bodies S and P when moving in an ellipse of which the transverse axis is $2a$.

POTENTIAL ENERGY OF THE SYSTEM.— The sum of the kinetic and potential energies is constant, but its absolute value is by "Absolute Value of the Energy of a Body Unknown," and not necessary to be known.

Hence if we assume that the potential energy is of the form

$$\mathrm{K}-\mathrm{C}\,.\,\mathrm{S}\,.\,\mathrm{P}\frac{1}{r}$$

the second term, which is the only one depending on the distance, r, is also the only one which we have anything to do

with. The other term K represents the work done by gravitation while the two bodies, originally at an infinite distance from each other, are allowed to approach as near as their dimensions will allow them.

THE MOON IS A HEAVY BODY.—Having thus determined the law of the force between each planet and the sun, Newton proceeded to show that the observed weight of bodies at the earth's surface and the force which retains the moon in her orbit round the earth are related to each other according to the same law of the inverse square of the distance.

This force of gravity acts in every region accessible to us, at the top of the highest mountains and at the highest point reached by balloons. Its intensity, as measured by pendulum experiments, decreases as we ascend; and although the height to which we can ascend is so small, compared with the earth's radius, that we cannot from observations of this kind infer that gravity varies inversely as the square of the distance from the center of the earth, the observed decrease of the intensity of gravity is consistent with this law, the form of which had been suggested to Newton by the motion of the planets.

Assuming, then, that the intensity of gravity varies inversely as the square of the distance from the center of the earth, and knowing its value at the surface of the earth, Newton calculated its value at the mean distance of the moon.

His first calculations were vitiated by his adopting an erroneous estimate of the dimensions of the earth. When, however, he had obtained a more correct value of this quantity he found that the intensity of gravity, calculated for a distance equal to that of the moon, was equal to the force required to keep the moon in her orbit. He thus identified the force which acts between the earth and the moon with that which causes bodies near the earth's surface to fall towards the earth.

CAVENDISH'S EXPERIMENT.—Having thus shown that the force with which the heavenly bodies attract each other is of the same kind as that with which bodies that we can handle are attracted to the earth, it remained to be shown that bodies such as we can handle attract one another.

The difficulty of doing this arises from the fact that the mass of bodies which we can handle is so small compared with that of the earth, that even when we bring the two bodies as near as we can the attraction between them is an exceedingly small fraction of the weight of either.

We cannot get rid of the attraction of the earth, but we must arrange the experiment in such a way that it interferes as little as is possible with the effects of the attraction of the other body.

The apparatus devised by the Rev. John Michell for this purpose was that which has since received the name of the Torsion Balance. Michell died before he was able to make the experiment, but his apparatus afterwards came into the hands of Henry Cavendish, who improved it in many respects, and measured the attraction between large leaden balls and small balls suspended from the arms of the balance. A similar instrument was afterwards independently invented by Coulomb for measuring small electric and magnetic forces, and it continues to be the best instrument known to science for the measurement of small forces of all kinds.

THE TORSION BALANCE.—The Torsion Balance consists of a horizontal rod suspended by a wire from a fixed support. When the rod is turned round by an external force in a horizontal plane it twists the wire, and the wire, being elastic, tends to resist this strain and to untwist itself. This force of torsion is proportional to the angle through which the wire is twisted, so that if we cause a force to act in a horizontal direction at right angles to the rod at its extremity, we may, by observing the angle through which the force is able to turn the rod, determine the magnitude of the force.

The force is proportional to the angle of torsion and to the fourth power of the diameter of the wire, and inversely to the length of the rod and the length of the wire.

Hence, by using a long fine wire and a long rod, we may measure very small forces.

In the experiment of Cavendish two spheres of equal mass, m, are suspended

from the extremities of the rod of the torsion balance. We shall for the present neglect the mass of the rod in comparison with that of the spheres. Two larger spheres of equal mass, M, are so arranged that they can be placed either at M and M or at M′ and M′. In the former position they tend by their attraction on the smaller spheres, m and

FIG. 17.

m, to turn the rod of the balance in the direction of the arrrows. In the latter position they tend to turn it in the opposite direction. The torsion balance and its suspended spheres are enclosed in a case, to prevent their being disturbed by currents of air. The position of the rod of the balance is ascertained by observing a graduated scale as seen by reflection in a vertical mirror fastened to the middle of the rod. The balance is placed in a room by itself, and the observer does not enter the room, but observes the image of the graduated scale with a telescope.

METHOD OF THE EXPERIMENT.—The time, T, of a double vibration of the torsion balance is first ascertained, and also the position of equilibrium of the centers of the suspended spheres.

The large spheres are then brought up to the positions MM, so that the center of each is at a distance from the position of equilibrium of the center of the suspended sphere.

No attempt is made to wait till the vibrations of the beam have subsided, but the scale-divisions corresponding to the extremities of a single vibration are observed, and are found to be distant x and y respectively from the position of equilibrium. At these points the rod is, for an instant, at rest, so that its energy is entirely potential, and since the total energy is constant, the potential energy corresponding to the position x must be equal to that corresponding to the position y.

FIG. 18.

Now if T be the time of a double vibration about the point of equilibrium O, the potential energy due to torsion when the scale reading is x is by "Potential Energy of the Vibrating Body"

$$\frac{2\pi^2 m}{T^2}\,x^2$$

and that due to the gravitation between m and M is by "Potential Energy of the System"

$$-C\,\frac{m\,M}{a-x}$$

The potential energy of the whole system in the position x is therefore

$$-C\,\frac{m\,M}{a-x}+\frac{2\pi^2 m}{T^2}\,x^2$$

In the position y it is

$$-C\,\frac{m\,M}{a-y}+\frac{2\pi^2 m}{T^2}\,y^2$$

and since the potential energy in these two positions is equal,

$$C\,m\,M\left(\frac{1}{a-y}-\frac{1}{a-x}\right)=\frac{2\pi^2 m}{T^2}\,(y^2-x^2)$$

Hence

$$C=\frac{2\pi^2}{MT^2}\,(x+y)\,(a-x)\,(a-y)$$

By this equation C, the constant of gravitation, is determined in terms of the observed quantities, M the mass of the large spheres in grammes, T the time of a double vibration in seconds, and the distances x y and a in centimeters.

According to Baily's experiments, $C=6.5\times10^{-8}$. If we assume the unit of mass, so that at a distance unity it would produce an acceleration unity, the centimeter and the second being units, the unit of mass would be about 1.537×10^7 grammes, or 15.37 tonnes. This unit of mass reduces C, the constant of gravitation, to unity. It is

therefore used in the calculations of physical astronomy.

UNIVERSAL GRAVITATION.—We have thus traced the attraction of gravitation through a great variety of natural phenomena, and have found that the law established for the variation of the force at different distances between a planet and the sun also holds when we compare the attraction between different planets and the sun, and also when we compare the attraction between the moon and the earth with that between the earth and heavy bodies at its surface. We have also found that the gravitation of equal masses at equal distances is the same whatever be the nature of the material of which the masses consist. This we ascertain by experiments on pendulums of different substances, and also by a comparison of the attraction of the sun on different planets, which are probably not alike in composition. The experiments of Baily on spheres of different substances placed in the torsion balance confirm this law.

Since, therefore, we find in so great a number of cases occurring in regions remote from each other that the force of gravitation depends on the mass of bodies only, and not on their chemical nature or physical state, we are led to conclude that this is true for all substances.

For instance, no man of science doubts that two portions of atmospheric air attract one another, although we have very little hope that experimental methods will ever be invented so delicate as to measure or even to make manifest this attraction. But we know that there is attraction between any portion of air and the earth, and we find by Cavendish's experiment that gravitating bodies, if of sufficient mass, gravitate sensibly towards each other, and we conclude that two portions of air gravitate towards each other. But it is still extremely doubtful whether the medium of light and electricity is a gravitating substance, though it is certainly material and has mass.

CAUSE OF GRAVITATION.—Newton, in his *Principia*, deduces from the observed motions of the heavenly bodies the fact that they attract one another according to a definite law.

This he gives as a result of strict dynamical reasoning, and by it he shows how not only the more conspicuous phenomena, but all the apparent irregularities of the motions of these bodies are the calculable results of this single principle. In his *Principia* he confines himself to the demonstration and development of this great step in the science of the mutual action of bodies. He says nothing about the means by which bodies are made to gravitate towards each other. We know that his mind did not rest at this point—that he felt that gravitation itself must be capable of being explained, and that he even suggested an explanation depending on the action of an etherial medium pervading space. But with that wise moderation which is characteristic of all his investigations, he distinguished such speculations from what he had established by observation and demonstration, and excluded from his *Principia* all mention of the cause of gravitation, reserving his thoughts on this subject for the "Queries" printed at the end of his "Opticks."

The attempts which have been made since the time of Newton to solve this difficult question are few in number, and have not led to any well-established result.

APPLICATION OF NEWTON'S METHOD OF INVESTIGATION.—The method of investigating the forces which act between bodies which was thus pointed out and exemplified by Newton in the case of the heavenly bodies, was followed out successfully in the case of electrified and magnetized bodies by Cavendish, Coulomb, and Poisson.

The investigation of the mode in which the minute particles of bodies act on each other is rendered more difficult from the fact that both the bodies we consider and their distances are so small that we cannot perceive or measure them, and we are therefore unable to observe their motions as we do those of planets, or of electrified and magnetized bodies.

METHODS OF MOLECULAR INVESTIGATIONS.—Hence the investigations of molecular science have proceeded for the most part by the method of hypothesis,

and comparison of the results of the hypothesis with the observed facts.

The success of this method depends on the generality of the hypothesis we begin with. If our hypothesis is the extremely general one that the phenomena to be investigated depend on the configuration and motion of a material system, then if we are able to deduce any available results from such an hypothesis, we may safely apply them to the phenomena before us.

If, on the other hand, we frame the hypothesis that the configuration, motion, or action of the material system is of a certain definite kind, and if the results of this hypothesis agree with the phenomena, then, unless we can prove that no other hypothesis would account for the phenomena, we must still admit the possibility of our hypothesis being a wrong one.

Importance of General and Elementary Ppoperties.—It is therefore of the greatest importance in all physical inquiries that we should be thoroughly acquainted with the most general properties of material systems, and it is for this reason that in this book I have rather dwelt on these general properties than entered on the more varied and interesting field of the special properties of particular forms of matter.

THE DRAINAGE SYSTEM OF PHILADELPHIA.

By RUDOLPH HERING.

Condensed from a Paper read at the Meeting of the Engineers' Club of Philadelphia.

It is a well-known fact that a large percentage of sickness in our city is due to defective drainage. The importance of considering a remedy is, therefore, apparent. It is my purpose to give a general idea of the ways in which our houses and streets are drained, and then to point out some of the defects, together with their remedies, which, if not securing a complete immunity from disease, would remove a powerful agency for the evil.

The house drains form the most important part of the drainage system. Upon the care bestowed upon them will, in a great measure, depend the ultimate success of the whole, from a sanitary point of view.

The whole matter is left to the plumbers. Although they may be excellent and conscientious workmen, they are gention of their work, or are prevented from erally not versed in the principles of the science governing the design and execucarrying them out by the unwillingness of the property owners to for pay them. Col. Waring has formulated the requirements of a perfect system of house drainage, as follows:

Allow no organic decomposition to take place within or near the dwelling or within any drain or pipe connected with it, under conditions favorable to the propagation of unhealthful influences.

Allow no air that has once been inside of a drain or soil pipe to enter the house under any conditions.

Let us see how far our house-drainage answers this formula. We have in the main three different systems.

First. The drainage of the soil-pipe discharges into a cesspool or well, and the waste waters are conveyed on the surface into the street gutters. This is the oldest and, until recently, most used, and is still designed for the many new houses built on streets without sewers. In old houses the wells are generally in the cellar, in the new ones they are in the yard. All wells being lined with bricks laid dry allow the liquid to soak away into the adjoining ground. We therefore do allow decomposition to take place in the well within or near our dwellings, and this under conditions favorable for spreading disease, and also allow air from the cesspool, especially when in the cellar, to rise directly into the house. The surface discharge of waste water is not injurious to the health because it facilitates oxydation. But it is annoying and disagreeable, partly

because we see it constantly, partly because it covers the sidewalks with ice in winter and endangers the comfort of pedestrians.

Second. All drainage is conveyed underground to the sewer, including the overflow from the cesspool. This system is the most common. The old cesspool, still used as before, is connected with the sewer, generally by an eight-inch terra cotta pipe. From this a soil pipe, usually of cast iron, four inches in diameter, is carried up to the water closets. Waste pipes, not over one-and-a-half inches in diameter, run from the kitchen, bath-room and washstands into the soil pipe or main pipe, but generally in a manner which requires the shortest length of pipe, whether this is beneficial to the inhabitants or not. The spouts are generally carried into the main pipe. Nearly always traps are put in under each place where refuse is received, as under the water closet, sinks and washstands; sometimes an additional main trap is placed where the pipe enters the cellar. The intermediate air-locked portion is connected with some pipe leading to the roof, generally a rain waterspout. Hardly one house in a hundred has its soil pipes ventilated properly, and hardly ever the waste pipes. No provision is ever made to allow fresh air to enter and circulate through the pipes. The work itself is generally done very badly, especially in the bonus houses. It is amazing how recklessly the drains are put into some houses, accomplishing in reality, in a far greater degree, just what they are intended to avoid.

But let us see the defects clearly by applying our formula. Decomposition is allowed to take place in the cesspools under conditions favorable to disease, as the sewage remains there a long time before the overflow carries it away, and the contaminated air, when originating in the cellar, rises immediately into and through the house. The absence of ventilation allows decomposition in the pipes, and, as the joints and fittings are often poorly made, allowing an escape, the poisonous gas reaches us often also directly from this source. During a heavy rain storm the sewer receives much water, the air is therefore forced out, and, as the manhole covers are tight, it blows out the weakest traps and enters our houses. It can be detected by the bubbling noise in the washstands and water closets.

Third. All drainage is conveyed directly into the sewer, solely through the pipes without having any cesspool on the premises. This is the latest system and the best. It leads, when properly designed and built, all refuse matter as directly and as rapidly as possible away from the premises. But the details are the same as before, with the same objectional features, excepting those of the cesspool. With the absence of proper ventilation, and of a most careful design and execution of all its details, it is impossible to have a system answering the requirements of health.

Why have we these imperfections? Because there is an entire absence of municipal regulations governing the details of house drainage. Proprietors and plumbers have their own way and carry out their own ideas. Water pipes are laid according to regulations. Gas pipes are carefully inspected as to their sizes, directions, bends, position, &c. But drain pipes, the contents of which have such a powerful influence on the state of our health, receive no attention whatever. The requirement, therefore, is that we should have municipal regulations in accordance with the latest information that the respective sciences furnish us; and the second that we should have an efficient system of carrying them out, by intelligent management, by licensed plumbers and by inspectors placed under bond.

Sewers are to collect the discharge from the dwellings and washings from the streets, and to convey them to places where they can do no harm. A sewer will never be anything but a powerful enemy in our midst, and if not under perpetual supervision will be able any day to proclaim a victory in some home. To reduce the evil to a minimum, it is absolutely necessary that all the works should be designed, built and maintained according to the latest and most approved methods of the science of sanitary engineering. The requirements of a perfect system of sewerage may be stated as follows:

A. To allow no decompositon of organic matter to take place under con-

ditions favorable to the propagation of unhealthful influences.

This can be accomplished under the following conditions.

First. Water-tight sewers.

Second. Rapid reception and conveyance, together with effectual discharge of all sewage and storm water.

Third. Proper ventilation.

B. To be readily accessible in all its parts.

This is accomplished by a sufficient number of man-holes and lamp-holes, serving at the same time as ventilators.

C. To be built with a uniformity of design and in the best practicable manner.

D. To be designed with reference to economy of first cost and maintenance.

We will now describe our sewers, aggregating in length nearly two hundred miles, state wherein they do not fulfill these requirements, and how the defects may be greatly improved.

The branch sewers have a clear diameter of 3 feet, and are originally circular in form. They are built of a 4″ ring of brick, the invert being usually laid dry and the arch built with mortar. After several years they are found to be more or less elliptical, the long axis being horizontal. Whenever well built this should not occur. If the ellipse is too flat, then the arch falls down. If it does not come to this, it has a form which gives for the usual flow about the greatest surface of friction for the amount of water, precisely the opposite of what is desirable for a perfect sewer, as the velocity is thereby diminished and a deposit caused. As the bricks are not laid carefully, the sides are very rough, which impairs the velocity of the flow, and allows solid particles to adhere and decompose.

There has been no sytematic provision for ventilation. Man-holes are built into the work at intervals of from 200 to 400 feet, but are covered with tight-fitting cast-iron lids.

The connections of the house drains with the sewers are made by the plumbers. The city reserves the right to inspect the connections; but, judging from the fact that by far the most breaks in our small sewers occur just where such connections have been put in, they cannot have been done very perfectly. We see that the most important of the above requirements have not been fulfilled. Our sewers are not water-tight, but allow sewage to soak into and penetrate the ground instead of taking it away. The flat bottom and the roughness of the sides reduce the velocity considerably, which either prevents the removal of the sewage before decomposition or actually causes a deposit. There is no ventilation, no ingress or egress of air, except by forcing the traps that lead into our dwellings. They are not built in the best practical manner, nor with reference to the cost of maintenance, which has been immense. About $100,000 are yearly expended to keep our sewers in repair.

A system answering the requirements to a far greater degree, would be a system of 12 and 15-inch drain pipes instead of 3 feet sewers. Their capacity is ample for the heaviest storms for a length of several squares. The whole city of Saratoga, including the drainage area of a small run, has been effectually drained by a single 3 feet sewer. Where the pipes are well laid they have given satisfaction. They are extensively used in the best drained cities of the world. Where badly laid, however, they are even worse than our present sewers on account of not being as accessible. The main advantages are as follows:

First. They are water tight when properly jointed.

Second. Owing to their smoothness they will rapidly receive and convey all sewage when carefully laid to the proper grades and curves. They will admit of a smooth and neat connections with the house drains, thereby likewise increasing the velocity.

Third. They can be properly ventilated. At present the prevailing opinion among sanitary engineers is that all sewers should have free communication with the atmosphere as often as possible through open manholes. The oftener the air in the sewer can be replaced by a fresh supply the better. The man-holes being the same a twelve-inch pipe would stand a much better chance of having its air renewed, as it contains only one-ninth as much as a three-feet sewer. As the flow is more rapid it would draw the air with it and help the exchange. As there is a quicker discharge and a smaller

surface exposed to the air there will be less occasion to decompose and vitiate the air.

Fourth. They can be readily accessible when properly built and provided with manholes.

Fifth. There is no experience, as far as engineering is concerned, that prevents them from being laid in a perfect manner; that is, with regular grades and lines, with perfectly tight joints, and with such foundations as will make an uneven settlement, breaking the pipes or joints very rare, if not impossible.

Sixth. They are as cheap as a three-feet brick sewer. The cost of maintenance would be much less, and they could be thoroughly cleaned by a stream from a fireplug.

The main sewers collect the discharges from the branch sewers, and convey them to the rivers.

By regulation the size of a main sewer shall be sufficient to enable it to discharge an amount of storm water equal to a rainfall of one inch per hour. The consequence is that our sewers are extremely large, and, as I believe can be shown, entirely too large. The matter is a serious one, as it involves a great amount of money. If the provision for a half-inch rainfall would be ample the cost of the sewers of our city would be diminished at least one million of dollars. Boston, Providence, New York and Philadelphia have, according to the Smithsonian contributions, about the same rainfall when the heaviest showers occur.

In Boston the sewers are calculated for one quarter inch rainfall, and have been found satisfactory. In Providence which has the best drainage system in the United States, they allow for a little over one half of an inch of rainfall and are perfectly well satisfied.

In New York, however, they calculate for one inch. But were the city not so peculiarly situated, being a long, narrow strip of ground between two rivers, which gives but small drainage areas, and, consequently, comparatively small and inexpensive sewers, their attention would likely have been drawn to the subject more closely on account of the vast expanse. In Philadelphia we also calculate for one inch of rainfall to reach our sewers. Our drainage areas being very large, the sewers, therefore, become immense. Leaving out the Wissahickon and Tacony creeks which two creeks ought never to be turned into a sewer, we have the Mill creek, draining about 3000 acres, requiring a sewer 20 feet in diameter and about 2 miles in length; the Heart creek, draining about 2000 acres, making the sewer from 13 to 16½ feet in diameter for 2 miles; the Honey Run sewer will drain over 4000 acres and at six miles above its probable outlet has already a diameter of fourteen feet, and so on. It can readily be seen what stupendous works we have in prospect. Roughly estimated, we will need at least $3,000,000 to provide for main sewers probably becoming necessary in the next twenty years. How important therefore, is the question of size! From personal observations I believe that we have never had a shower sufficiently heavy to fill any of our largest sewers, provided they were not tide-locked and otherwise improperly built, except, perhaps, at the entrances, where the water is naturally dammed up. Experience tells us that only a portion of the rain-water finds its way into the sewers. The rest is either evaporated or absorbed, especially when we have the heaviest storms.

We also know that it takes considerable time for the rain water to reach the sewer and to flow through it, the storms often ceasing in the meantime. As main sewers are massive and strong, they can stand a considerable upward pressure in case they should be completely filled. From all these facts it is evident, I believe, that we could reduce the size of our sewers perhaps one half without running any risk. And if there should be some damage to pay occasionally for the flooding of a few cellars, which is not even probable, if safeguards are provided, would it not be more economical than to spend more than a million for an increased size? Here also can be said, the smaller the sewers the easier it is to ventilate them, and the greater will be the velocity for the same amount of sewage and the more effectual the discharge.

The *shape* of our main sewers is circular; occasionally they have a flat bottom. There should be a distinction made in the design between arch and

invert. The arch must resist external pressure, for which the science of statics gives readily the best form for any conditions. The earlier sewers have not been satisfactory in this respect. Only those built during the last two or three years have answered the requirements of stability and good workmanship. The shape of the invert should be governed by another element. That is, in order to be self-cleaning the sewers should give the greatest possible velocity to the ordinary flow. This can be done best by the egg-shaped section, which is extensively used in the best drained cities, and answers admirably. In Philadelphia it has not been used. The results from not doing so can be observed in many sewers.

Ventilation has not yet been systematically introduced. How much study is still required to obtain a satisfactory conclusion may be seen from the fact that in London large ventilating shafts have proved a failure, and in Frankfort, the best drained city in the world, they have been a success.

The whole subject, especially the house drainage, needs sincere and early attention and study. But, more than that, it needs *action*. Much has been said by physicians and engineers, but almost nothing has been done. We hear continually something said about our bad drainage, but few seem to know just where the technical imperfections are. As I have given the matter some study, and as it seems to be justly of general interest to the community at present, I thought it a seasonable subject to present to you this evening.

THE DRAINAGE OF LAKE FUCINO.

By A. BRISSE and L. DE ROTROU.

From the "Abstracts" of the Institution of Civil Engineers.

Fucino was the largest lake in Central or Southern Italy, situated in the province of Aquila. It covered the greater part of a vast table land belonging to the territory of the subprefecture of Avezzano, a small town rising at a little distance from its shores. This tableland is one of the largest to be met with in the central part of the Apennines, and is surrounded on all sides by spurs of the main chain of mountains, thus forming a vast basin entirely separated from the adjacent valleys, so that the rain waters falling within its limits possessed no outlet by which to discharge themselves into the neighboring rivers. The area of this basin is 173,000 acres, and the surface waters of the lake on the 10th of June, 1861, stood at 2,094 feet above sea-level. In consequence of the peculiar conformation of this basin, having no communication with any of the adjacent valleys, and the waters collecting in it having no subterranean or other outlet—no means of escape, in fact, but by evaporation or absorption—it frequently happened that, owing to excess or deficiency of rainfall, the level of the lake either rose or fell beyond its normal levels; in the former case inundating the valleys on its borders, and in the latter producing unhealthiness from its exposed banks. Julius Cæsar was the first to conceive the idea of draining the lake; it was attempted by Claudius, and the works which he caused to be executed were considered by Pliny as the most extraordinary of that age. The attempt of Claudius was renewed by Trajan and by Hadrian, and in the middle ages by Frederic II., perhaps also by Alphonso I. of Aragon, and by several sovereigns of Naples but always in vain.

The area of the lake naturally fluctuated from time to time, but its average dimensions were about 37,050 acres. In form it was very nearly elliptical, its greater axis, running from northeast to southeast, was about 12.4 miles long, the shorter one nearly 7 miles. Its bottom sloped very gently downwards from west to east, and at about 7.4 miles from the head of the tunnel constructed by the Romans to drain the lake the bottom was very nearly level, and constituted the lowest part of the basin. Beyond

this level part, the bed rose again towards the east, but with a much steeper gradient. Owing to the amount of earth annually washed into the lake, it was calculated that its bed had risen 15.65 feet since the time of the Emperor Claudius, when its depth is assumed to have been about 53.723 feet.

The most important, as well as the nearest, of the valleys situated on the other side of the mountains which gird the Fucino basin, is that of the Liris, which, to the west, runs parallel for a certain distance with the plateau of the lake, but at a lower level. The river is about 3¾ miles in a straight line from the lake but between the two there is a mountain, Mount Salviano, and another plain called the "Campi Palentini," higher than the lake. As the position of the latter precluded the possibility of making an open cutting between it and the river Liris, the Emperor Claudius determined to excavate a tunnel through Mount Salviano, at about 984 feet below its summit, and under the Palentine fields at an average depth below the surface of 328 feet, in order to discharge the water from the Fucino into the river Liris at a sufficient height above the latter to enable it, even when in flood, to receive the water from the mouth of the tunnel. This tunnel had its outfall at a level of 41.487 feet above the Liris, and was constructed on a gradient of about 1½ in 1.000. As far as could be judged by the ruins of the tunnel, which it was found necessary to demolish in order to replace it by the tunnel of Prince Torlonia, it had a cross section of 11.9 square yards, and its head is supposed to have been somewhere about 3¾ feet above the then bottom of the lake. In the construction of this tunnel the Romans sank about forty shafts, twenty nine between the foot of Mount Salviano and the river Liris, and the remainder between the mountain and the lake, ranging from 57.72 feet to over 400 feet in depth. One of these shafts which was opened whilst constructing the Torlonia tunnel, was found to be square, each side measuring 14.16 feet and supported in the middle by strong cross beams dividing the shaft into four equal compartments. The tunnel of Claudius was 6,178.59 yards in length and it passed through the following soils in its course from its outfall to its head :

	Yards.
Compact limestone rock	708.26
Detached blocks accumulated on the slope of the compact rock	251.30
Pudding stone, composed of rolled gravel embedded in calcareous cement	944.35
Detached blocks	85.25
Compact limestone	826.30
Detached blocks	118.04
Clay and sand	751.98
Detached blocks	118.04
Compact limestone	891.88
Broken rocks in the center of the mountain	426.27
Compact limestone	453.59
Softer limestone	555.24
Clay	48.09
Total	6,178.59

It will be sufficient here to state that although water is said to have flowed through this channel, its inefficiency soon proved itself, and an accident closed up the tunnel altogether for all practical purposes.

In 1854, however, Prince Alexander Torlonia decided to carry out the drainage of the lake at his own expense, and he entrusted its execution to M. de Montricher, who was assisted by M. Henri Bermont and M Alexander Brisse.

In determining the section to be given to the Torlonia tunnel the conditions of possible rainfall and the capacity of the Liris to receive the discharge were considered. On the former point much uncertainty existed, but M. de Montricher came to the conclusion that under no circumstances should a volume of water greater than 11,000 gallons per second be discharged into the Liris, and this quantity was also found to agree with that of the supply of the lake during a hypothetical rising of 5 feet 10 inches in two months. M. de Montricher, therefore, resolved upon a tunnel having a cross section of 216 square feet and a general slope of 1 in 1,000, and following generally the Roman tunnel which might thus be utilized as a headway.

The new tunnel is egg-shaped in section, truncated at its small base, and resting on an invert 9.3 feet in span, with a versed sine of 9.6 inches. The greater axis measured 19 feet from the bottom of the invert to the crown of the arch; the lesser one, 13.1 feet at a height of 12½ feet above the bottom of the

invert, which gives a profile having an area of 211 square feet. The slope is generally 1 in 1,000, and with a depth of water of 17.25 feet upon the invert, the discharge is 11,000 gallons per second. The datum point was fixed at the outfall of the tunnel, 33 feet above the bed of the river and 8½ feet below the Roman invert at that place. The deepest part of the lake was at this time 48 feet above datum, and at a distance of 11 miles from the bench-mark at the outfall. The surface of the lake was 98 feet above datum, and its depth 50 feet. The invert of the Torlonia tunnel, at its outfall on the Liris, was placed 6 feet above datum; or 2.65 feet lower than the Roman tunnel at that spot. Thence it is carried at a slope of 2 in 1,000 for the first 393 yards, and at 1 in 1,000 for the rest of its length.

The works were commenced by the construction of a dam, to be cut off the waters of the lake from the head of the Roman tunnel. This dam was formed by two parallel arms, 240 yards distant from each other, and connected by a curve of 120 yards radius, its total length being 1,640 yards. Its top was protected by a strong stone revetment, and for further protection an inner dam was also constructed, with a space between the two of about 32 acres. About 196,200 cubic yards of earth and 39,300 cubic yards of stone were employed in the constructing of these works. The tunnel was commenced at the outfall towards the end of 1855, the greater part of it being constructed with hewn stone, brickwork being only occasionally introduced. Considerable difficulties were experienced during the progress of the work, owing to the quantity of water met with in the shafts, the workmen having sometimes to labor in water and mud up to their waists. As soon as the first 5,084 yards of tunnel had been completed, a communication was opened with the old Roman tunnel, into which the waters of the lake were directed, in order to reduce the head before completing the works. This preliminary draining lasted four hundred and seventeen days, and reduced the level of the lake by 14 feet, after which the tunnel was continued as far as the head of the Roman work, when a second draining of the lake was commenced, a canal being cut to direct the waters of the lake to the tunnel. The surface of the lake, at the completion of this draining was lowered another 25 feet, its depth reduced to 18½ feet, and its area to 23,230 acres. The tunnel was completed in November 1869 to a length of 6,887 yards, of which 2,813 yards were excavated through the compact rock without revetment, 344 yards through pudding stone, and lined with brick, and 3,729 yards through clay, detached rocks, &c., and lined with strong masonry of hewn stone. For its construction twenty-eight shafts were sunk or repaired, having an aggregate length of 1,560 yards, and two inclined galleries, together 568 yards long. The deepest of the shafts made use of for removing the excavated material was 154 feet, and the shallowest 55.44 feet. Twelve of the twenty-eight shafts were above 279 feet in depth. For the last 22 yards of its length the tunnel gradually widens and at its mouth is divided by a cutwater into two small tunnels, each of which is fitted with a sluice gate; and 7 feet advance of this is the real entrance, consisting of a semicircular arch in springing from vertical side walls 197 feet apart, and in front of this again is a regulating basin. In order to drain the lower part of the lake, a canal was excavated leading to the head of the tunnel, having the same capacity as the tunnel itself, and a slope of 1 in 6,959, its bottom width being 49.21 feet, and its sides having a batter of 45°. This canal, 8½ miles in length, was formed by dredging, effected whilst the waters were still being drained off from the lake. The further works undertaken to complete the reclamation of land consisted of 130 miles of roads, 62 miles of canals and drains (inclusive of the main canal, but exclusive of the tunnel), and 402¾ miles of ditches, and the land reclaimed amounts to 35,012 acres.

The total aggregate cost of this work to Prince Torlonia was 43,137,208 francs or about £1,800,000. Of this a little over £1,000,000 sterling was the cost of the tunnel, canal, and drainage works generally; £600,000 for compensations, roads, bridges, drains, and incidental expences, including 5 per cent. interest on capital during construction of the works, and something under £200,000

for preliminary expenses, purchase of concession, contribution towards improving the channel of the river Liris, and other minor incidental charges.

It is calculated that, by the increase in value of land previously cultivated, the drainage of Lake Fucino has added £160,000 to the wealth of the proprietors along its shores, which it is expected in the course of a few years, will still further increase. In addition to this there remains the 35,012 acres reclaimed from the lake, the proprietary of which is vested in Prince Torlonia in return for his expenditure in the construction of the works.

PROGRESS IN FIELD-GUNS.

From "The Engineer."

SUFFICIENT has transpired to show that, in their efforts to produce an improved field-gun, the authorities connected with the Royal Gun Factories have been gaining fresh light of great value as to the conditions of success. One element of accuracy in the shooting of breech-loaders has been very clearly ascertained and will be appropriated for the benefit of muzzle-loaders. When a gun is loaded from the rear the shot of course goes in first. This being the process, it has been necessary to fix the position of the shot by some mechanical arrangement, independently of the powder charge. Hence the powder chamber has been made to retain an unvarying capacity, and it has been perfectly practicable for each round to possess exactly the same elements. Consequently, when shooting for accuracy, a very neat diagram has been made, it being possible to lodge the several shots very close together. The muzzle-loader having its shot rammed down upon its cartridge, has been subject to varying degrees of pressure on the latter, and a varying position of the shot. Weight for weight any number of rounds might be exactly the same but the capacity of the powder chamber might be rarely twice alike. What this involves has been strikingly apparent in the experiments with the 80-ton gun. A gun is loaded not only with powder and shot but also with air, and the proportion of the latter affects the burning of the cartridge, the pressure set up in the gun, and the velocity imparted to the projectile. If a breech-loader has the same weight of powder and shot in a succession of rounds, it also has the same bulk of air behind the shot. The makers and advocates of breech-loaders were apparently unconscious until lately of the advantage which they gained in this respect. But the matter is well understood by Herr Krupp at the present time. The principle being apprehended, there is no reason why it should not be applied to muzzle-loading guns, and this is the point which has now been reached. The varying air space in the different rounds probably accounted for the defective shooting at high angles during the Eastbourne experiments.

There is no need for any more of this, and the new field-gun will unquestionably be provided with better appliances for securing a fixed capacity in the powder-chamber. It is also possible that we may see some change in the position of the copper gas-check. Herr Krupp places his gas-check—at least in some of his recent guns—a short distance in advance of the base of the shot, the gas check being a ring or band instead of a disc. As this tends to weaken a projectile, it would be an objection in an armor-piercing shot or shell; but the objection would not apply in the case of field artillery. There are certain advantages in such an application of the gas-check, and though there may be some mechanical difficulty in employing this method with muzzle loaders, it would seem that something of the kind can be effected. As for the rifling, it is unquestionable that we are bidding good-bye to the studs, and that rotation is to be obtained henceforth from the gas-check, in conjunction with the polygroove system.

Until very recently the breech-loader had an advantage over the muzzle-loader

in the position of a powder chamber. The enlargement of the bore at the lower end of a rifled breech-loader was not adopted originally for the sake of using a shorter cartridge or a larger charge, but in order to make room for the entrance of the lead-coated projectile.

Afterwards it was discovered that other benefits accrued. The action of the powder charge in a gun not being so well understood as it is now, it was thought that if a muzzle-loader were chambered, it would be necessary to have a cartridge of peculiar construction, so that when rammed home it should expand laterally and occupy the enlarged diameter. But the big gun has taught us that it is well to have some amount of space unoccupied in the powder-chamber, and accordingly there is no peculiar difficulty in the use of a chambered muzzle-loader. In fact, if it is thought desirable to make the cartridge swell out so as to fill the diameter of the chamber, it becomes necessary to create an air-space inside the cartridge by means of a hollow cone or similar contrivance, which, in the case of the 80-ton gun, is utilized for the transmission of a flash through an axial vent, whereby the cartridge is fired centrally, thereby preventing or diminishing those waves of pressure which act locally with abnormal force.

Two new field-guns, designed and manufactured by Sir W. G. Armstrong & Co., have been fired at the proof butts on the Government ground at Woolwich, and are about to be tried at Shoeburyness for range and accuracy. One is a muzzle-loader, and the other a breech-loader. The trials with the experimental 12-pounder of the Royal Gun Factories are still in progress, and very important results have been achieved. How these will compare with the performance of the Elswick guns remains to be seen. The gun itself is not the only question. There are many details connected with the projectile which enter largely into the efficiency of the weapon. In respect to velocity, the experimental 12-pounder of the Royal Gun Factories appears to be very efficient. Col. Owen, in his recent official "Treatise," has given the velocities attained with this piece as ranging between 1550 feet and 1700 feet per second. We believe that even a higher velocity than the latter has since been obtained, but it is not considered desirable to employ such a velocity in the service.

The Government Gun is chambered, the dimensions of the powder-chamber being given in the "Treatise" as 8 inches in length, and 3.6 inches in diameter, the powder charge ranging from 2.75 pounds to 3 pounds. These data may now be departed from, but the total length of the gun probably remains unaltered, namely, 83 inches. The calibre is given as from 3 inches to 3.2 inches and the weight 8 cwt. The question of field guns is now one of great importance, and the impending changes possess much interest.

MANUFACTURE OF GUNPOWDER WITHOUT WATER.

From "Engineering."

SINCE the general adoption of rifled cannon not a little attention has been given to the improvement of the powder employed for these weapons, the object having been to obtain a powder which would be at once little injurious to the gun, and would have a satisfactory uniform ballistic force. A commission was appointed in Russia in 1871 to study this question. One of its members, Colonel Winer, taking up the idea once suggested by Saint Robert, proposed to manufacture powder without employing water, and by compressing the materials at a temperature a little higher than that of the fusion of sulphur.

The advantages of powder thus prepared are as follows:—(1) Its hygrometric property is diminished, and so it is less affected by remaining long in damp places. (2) The manufacture is less expensive, because drying-rooms are dispensed with, and the mixture of the constituents takes place in mixing drums

instead of mills. (3) The danger in manufacture is diminished. As the drying operation takes a long time, large quantities of the material are necessarily accumulated in the drying-rooms whereas, when the powder is prepared directly in the dry state, only small quantities are treated at one time.

Winer was charged to make experiments in this direction in the works at Okhta, and he made the necessary arrangements for the purpose. The latter consisted of a hydraulic press, to which were adapted two hollow plates of copper connected by two pipes of the same metal for the passage of steam. The lower plate was screwed on the plate of the press which was fixed on the piston, and communicated, through a caoutchouc tube, with the steam pipe. The upper plate was fixed and put in communication with the steam pipe by means of an iron pipe. The pulverulent and dry mixture, prepared in the drum, was spread uniformly on the lower copper plates, then the piston was set in motion, and pressure was produced for ten minutes. The disc of powder thus obtained was a perfectly homogeneous mass. The temperature of the steam was about 120 deg. C. With a pressure of 130 atmospheres, measured in the manometers, cakes were got with a density of 1.80 to 1.9; with 30 atmospheres, it was 1.66 to 1.7. These pressures correspond respectively to 114 k. and 25.4 k. per square centimeter. The cake was reduced to grains by means of crushing cylinders. By means of a sieve the grains were isolated from the rest of the powder; and, lastly, they were discharged into bags.

The comparative experiments made in 1871 with the compressed powder and ordinary powder were not considered satisfactory, and merely gave an impulse to fresh experiments. Only in 1874, after having experimented with a long series of compressed powders of different grain and density, did Winer find one which answered the requirements. This powder had a density of 1.6, a grain of 6 to 8 m., and gave with a charge of 2.250 k. in a long range 4-piece, an initial velocity of 471.5 m in the projectile. The tension of the gas was 1366 atmospheres.

The new powder was next compared with ordinary powder with reference to hygrometricity. In a vessel filled to about a fourth of its height with water were arranged 0.10m. above the surface of the water, two sieves containing, the one 24.6k. of ordinary Okhta large grain powder (density of 1.75 grains 6.3 mm to 10.2 mm) and the other the same weight of Winer powder (density, 1.6: grains, 8.9mm. to 10.2 mm.) The vessel was closed with a lid covered with wax cloth, and left in the open air from August, 1875 to 25th October following. On re-opening it the grains of the ordinary powder were found covered with moisture, black, and so soft that, under pressure with the fingers, they were also slightly coated with moisture, but still quite firm, and they could only be crushed with pretty strong pressure. The former powder contained 6.75 per cent. of moisture, the latter 2.1 per cent. The firing of the long-range 4-piece with these powders, first dry, then moist, gave the following result:—

Species of Powder.	State of Powder.	Charge.	Initial Velocity.	Maximum tension of gas.
		k.	m.	atm.
Winer powder	Dry	2.050	438	919
	Moist	2.050	388	778
Ordinary large grain Okhta powder.....	Dry	2.350	456.3	1245
	Moist	2.350	323.1	641

The Winer powder lost by its lying in the vessel 11.4 per cent, of initial velocity, and the ordinary Okhta powder 29.2 per cent. The two samples of powder were then subjected to slow drying, at the temperature of 10 deg., from 26th October, 1875, to 5th January, 1876. At the end of this operation the ordinary powder was porous, and rugous in aspect, with efflorescences of saltpetre. The Winer powder, on the other hand, presented nothing abnormal. In firing these two powders so dried gave the following result:—

	Charge.	Velocity.	Tension.
	k.	m.	atm.
Winer powder....	2.050	434.6	1212
Ordinary powder.	1.840	421.5	1166
Ordinary powder.	2.050	443.8	1390
Ordinary powder.	2.250	473.3	1620
Ordinary powder.	2.350	476.6	1660

Thus the Winer powder gave nearly the same velocity as before the humidity test, whilst the ballistic properties of the ordinary powder were sensibly modified.

Colonel Winer further submitted to the humidity test two other samples (or ordinary powder with grains 6.3mm. to 10mm., and 1.75 density; Winer powder with grains 5mm. to 6.3 mm., and 1.6 density) which remained two weeks and a-half enclosed in the vessel. The results of firing were these:—

Species of Powder.	State of Powder.	Charge.	Velocity.	Tension.
		k.	m.	atm.
Winer powder .	Dry	1.95	457.5	1704
	Moist	1.95	457.8	2200
Ordinary Okhta powder.....	Dry	2.35	456.3	1245
	Moist	2.35	417.0	2060

Thus with the moist Winer powder there was no loss of velocity, while with ordinary powder the velocity was diminished 8.6 per cent. The experiments were conclusive as regards the relative hygrometricity of the two species of powder.

It is easy to account for this difference of property with ordinary manufacture. The water used in moistening disappears in the drying process and leaves in the grain small channels or pores, by which the moisture enters afterwards. Such channels do not exist in the powder manufactured without water.

The new powder is now being experimented with in Russia on a large scale for field guns. Colonel Winer has received an order for 82,000k of it. But hitherto it has not been found possible to prepare a powder of this kind, suitable for 8 inch, 9 inch, or 11 inch cannon and capable of replacing prismatic powder. The above experiments are described in a recent number of the *Journal d' Artillerie Russe.*

MECHANICAL TRACTION ON TRAMWAYS.*

By Mr. J. L. HADDAN, M.I.C.E.

From "Journal of the Society of Arts."

Before mechanical traction on tramways can be expected to attain the success to which its public convenience entitles it, it is necessary that the question shall be treated as such a radical change in locomotion deserves. The conditions to be imposed upon the machine and the system generally, should be clearly set forth, leaving it to manufacturers to meet them in the most economical manner possible.

The persons whose duty it is to impose these conditions are the following :—The Board of Trade, the civil engineer, the locomotive superintendent, the traffic manager, and the public. Every engineer now accepts that the following theories, although they will work, are anything but commercially sound, and should be abandoned when possible, viz.: —(1) Dead weight is a necessary power (adhesive) on a rising gradient; (2) dead weight is a necessary power (brake) on a falling gradient. If, on the moderate grades of a railway made artificially so as to meet the limit allowed by the above theories these main principles of railway traction are to be regretted, how much more so would it be the case were we to allow these tenets to influence tramway traction, where the grades are not only steeper but unalterable. The engine manufacturer, therefore, is not the proper person to be entrusted with these grave interests. A rapid street transport service is a public necessity, especially in cities where no underground communication exists, or in districts not served by it. In cities, where the streets are comparatively narrow, acceleration of the through traffic is positively a necessity, being probably the only proper means of relieving pressure; instance London Bridge and its approaches. If all the slow and ponderous wagons which now choke the bridge were, by means, say, of a prohibitive toll, forced to use Southwark Bridge, the general stream of traffic could be so accelerated as never to jam, even if the traffic were two-fold what it is. So far as an irregular traffic is concerned, like the Cassel steam tramway, where the summer service is considerable and the winter service *nil*, steam has decidedly the ad-

* A paper read before the Society of Arts.

vantage, as, when not in work, the engines cost nothing to keep; but for regular traffic it is only where considerable speed can be permitted, or in situations where greater loads than two horses can manage are required, that steam can compete successfully with horses.

After twelve months' working with twenty-five engines running about 300 trains a day, the following are a few of the leading rules which the experience gained warrants, I think, my laying down with a certain authority, under the five headings before mentioned:

The Board of Trade.—(1) The officers of the Board should have certain clearly defined executive powers, so as to insure their recommendations being properly carried out; the power of entire suppression, the only one they now possess, is too severe to be of any use, as it could not be applied severally to the innumerable details, the neglect of which afford such just grounds for public complaint. (2) Each company using steam shall be bound to furnish returns every month of the performance of the engines both active and passive, as also the amount of fuel, oil, &c., used. (3) The steam tramway traffic shall be worked in the opposite direction to the ordinary traffic, if a double line; with a single line this must naturally be the case in one direction. (4) In streets of less than a specified width no steam-car shall stop to take up or set down passengers. (5) On routes where the width of streets is less than a specified number of feet, steam trams shall take up passengers at certain defined points, but may stop where required to set down. (6). In any collision taking place, except at a cross road, the public vehicle shall *prima facie* be held responsible. (7) Any loaded wagon or cart, breaking down on the rails, and thus obstructing the tramroad, shall be deemed responsible, if it is proven that it could have circulated clear of the rails, and was not forced by the narrowness of the street, or other cause, to use the tram space. (8) On approaching all main cross roads used by omnibuses and trams, or where the traffic is considerable, the steam-trams shall slacken speed; and stopping stations, with this view, shall be as often as possible introduced at the arrival side of a cross road, and never be authorized elsewhere. Where cross traffic may be considerable, and it may not be deemed necessary to establish a station, then police caution notices to the general public shall be conspicuously posted. (9) To prevent undue speed, and insure a regular service, a time-table shall be drawn up, in which each departure and arrival shall be clearly defined, and each engine or car shall bear a distinguishing letter or figure corresponding to its own series of journeys. (10) As a further check on undue speed, the diameter of the driving wheels may be limited to two feet, so as to render quick speed wasteful, and therefore not likely to be encouraged by the management. (11) The fire-box shall be of such capacity as not to require the fire-door to be opened either during the run or at a crowded terminus. (12) Superheating the steam and attenuating it will be provisionally accepted on suburban lines in lieu of condensation, provided the beat of the exhaust be completely silenced, and the chimney be carried up fifteen feet above rail level, when outside passengers are carried. (13) In crowded cities no smoke or steam will be permitted to be visible. (14) Gauge-glass cocks to be so arranged as to be self-closing in the event of a gauge-glass breaking, so that the exit of steam or hot water shall be instantly or automatically arrested. (15) The fender back and front of the engine shall not be deemed suitable unless the clearance above the rails shall always be maintainable at the minimum, notwithstanding wear of brasses and wheels, which is usually allowed for by using a clearance so excessive as to be useless as a protection. (16) No movable points and crossings shall be used with steam traction, unless the needless be lockable, and no movable points of any kind shall be permitted in cases where the road can be laid (as it nearly always can) with fixed points only. (17) In all cases where the load exceeds the weight of the engine, or when two or more cars are coupled, either a special breaksman shall be obligatory or a continuous brake, worked from the engine, shall be attached to the train. (18) The engine shall be fitted with such apparatus, or appliances, that, should it leave the rails, or otherwise break down, five minutes shall

suffice to clear the road, with the assistance only of the staff of the train. (19) The running front of the engine shall be fitted with projecting reflecting lights, so that not only a disc of light shall be shown, but the whole of the front of the engine, and ten feet of the roadway in advance shall be brilliantly illuminated. (20) No machine shall at any time be left standing on the highway without its proper attendants, whose name or names shall always be conspicuously displayed on their engine. (21) No tram engine shall be allowed to be driven by one man where the variation of pressure shall range more than three atmospheres, or the fire require any attention, or lubrication be necessary, or the boiler require other than self-acting feed during a five-mile run, or any action be necessary which may necessitate the driver diverting his attention from driving. (22) In laying the pavement, the blocks shall be so laid as to define on the road itself the exact overhang of the tram vehicle, so that the public may judge when they are "standing clear."

Civil Engineers.—The grooved tram rail has been far too hastily adopted by the profession, seeing that compared with railway traction it will, when dirty, increase the tractive force about fourfold, which amounts on inclines, to almost as much resistance as if asphalte were used. In fact, the only notable advantages a tram rail possesses over a smooth road, say of wood or asphalte, is that it affords direction, without which speed would not be feasible; but as this advantage is not made use of, the value of a tram rail is certainly not at present worth its cost, nor does it warrant the wholesale cutting up of first-rate roads, which experience shows us can never be kept in perfect repair afterwards, owing to the great disparity in hardness existing between the rail and the road material. In America, where roads are bad and carriages few, this difficulty is sufficiently met by using a broad flat tread to the rail, so as to encourage carriages to run on the track itself. I must qualify the above so far as to explain that though a pair of horses can pull more on a tramway rail than on a wood or asphalte pavement, when on the level, a gradient less steep than the mean of most tramways soon brings the two to an equality; and in some cities where the average grades are heavy, the horse traction on the wood would prove to be the lighter of the two. It is a fact within my own knowledge, that on mounting the incline of the Avenue Josephine in Paris (one in twenty-five), the coachman applies the brake slightly by way of affording relief to the horses in the pull back on their collars, resultant of the effort of the car to recede being thereby eased. In Paris, with a view of diminishing the traction, especially on sharp curves, the groove on the rail is allowed to be as much as $1\frac{1}{4}$ inches; but do what you will to assimilate a tramway to a railway and obtain similar tractive facility on it, success is impossible, at any rate with a grooved rail. Both on road tramways and on common roads the secret of success lies in abolishing entirely a drawn load, for which a perfectly smooth road is required, in favor of continuous driving, and its antithesis, continuous breaking, a system which does not require too smooth a track, although it will work equally well on either—say, on ice or on sand.

The advocates, therefore, of combined engines and cars are so far traveling in the right direction, but (1) they do not utilize more than sixty per cent. of their weight for adhesive purposes instead of the whole; and (2) the working objections detailed under the heading Locomotive Superintendent will be found insuperable. The undue overhang of the cars produces violent longitudinal oscillations when drawn by steam; these shocks are not only disagreeable, but destroy the stock and road; the remedy hitherto has been the adoption of a long but flexible wheel base; but all the systems tried, without exception, were not at home at the tangents of the curves; for the pair of wheels first on the curve always skewed prematurely those remaining on the straight. Cars for use with steam, if they carry outside passengers, must be greatly stiffened and braced longitudinally, since when the brake is suddenly applied below, it fails momentarily to check the impetus of the passengers on the roof. In Brussels, an articulated train, after the design of M. Dathis, a French engineer, will be tried in a few weeks. The engine is detachable, and the cars (or each articulation)

have only one pair of wheels. The weight of the cars at the joints is supported by girder-like couplings, centered on the axis of each articulation. It is expected to work on curves of twenty feet radius. Considering that in Paris streets one litre of water will thoroughly cleanse a square meter at a cost of about 2d. per annum, it is surprising that tramway companies have not made joint arrangements to wash the streets. The saving in wear and tear to themselves and the general public, let alone the comfort, would amply justify the outlay.

Locomotive Superintendent.—(1) For the sake of economy in repairs, no tram-engine should run more than ten, or, say, twelve, hours daily. (2) To ensure due care and economy in the driving, every driver must have his own engine, and no one else be suffered to touch it. (3) During the day it was found necessary to sweep the tubes, and also to inspect and clean the machinery, as it could not be properly done, either morning or evening, in the dark. (4) Reliefs were performed by changing the engine bodily on passing the depot, and therefore without inconveniencing the passengers; when, however, a car broke down, every one had to change carriages, and the conductors were in despair as to who had paid and who had not. (5) Owing to the grease and dirt attendant on a running shed, it was found impossible to keep the cab in as decent order as the corresponding car; it was, for this and other reasons, abandoned in favor of an open iron weather shelter. I am decidedly of opinion that a detached engine is a *sine qua non*. (6) Rigid underframes should be condemned, as also crank angles, owing to the cross bending strains incident on an irregular road; coupling rods, because of the curves; and eccentrics and open axle boxes, by reason of the mud. (7) Volute springs have not been found to answer, the old C spring is far superior in distributing the shock. (8) Free play to the horizontal boiler, both laterally as well as longitudinally, is imperative, as, if fixed, it is so affected by the curves that the tube plates converge and tight tubes are an impossibility. (9) The brake should never be applied on the wheels, but on false tires readily renewable. They should be applied on both sides of the engine, and should not be arranged so as to strain the coupling rods, by either forcing the wheels together or driving them apart, nor should counter-balanced wheels be used. These remarks apply also to the cars. (10) The joint surfaces should be nearly double what is usual in a locomotive, owing to the constant use of the reversing lever and endless stoppages, which, in other ways, also tax the engine severely. (11) The steam chests should, as in Mr. Brown's Winterthur engine, be upside down, so as to drain the cylinders, and thus avoid the use of pet cocks. All the wearing surfaces should be excessive, and liners used wherever possible. (12) The machine must be powerful enough to push before it to the nearest siding any train which may break down, a further nut to crack for the combined car. (13) Side fire-doors are undesirable; they have been found to raise the tube plates by admitting cold air currents.

Management.—Steam traffic has to be managed on an entirely different basis to horses or railways. Steam traction in Paris now pays nine per cent., while the tramways and omnibuses are earning little if any dividend, although horse keep is cheap and fuel is dear. On making the usual false comparison, viz., per mile only, instead of per mile in conjunction with the weight carried (receipts), which is the only fair plan, since it represents work done, we find the cost in favor of horses. But when we reduce the competitors to the test of work done, as in column A, the result is greatly in favor of steam. See table:

(*See Table on following page.*)

The fares of the car of forty-eight passengers, when full, represented 3s. per mile on the line in question; but on certain days, owing to constant mutations, the earnings have been known to amount to 5s. 9d. per mile. The useless number of journeys run by the horses, and the value of the consequent extra dead weights, may be fully realized when the receipts only averaged 1s. 2½d. The cost of steam traction, with two full cars instead of one, is only increased ¾d. per mile for fuel and oil, which brings the cost per mile up to 8.18d. (in France), or less than horse traction on a far easier line with only one car. In

PARIS.—TABLE GIVING COMPARISONS BETWEEN HORSE AND STEAM TRACTION.

Classification.	Nature of road.	Working expenses per mile run.	Receipts per mile run.	Receipts per seat, averaging 0.45d. per mile.	A. Working expenses per mile. Work done equal in all three cases.	
			s. d.	d.	d.	
Steam.....	Steep.....	7.43	2 8	0.66	7.43	
Horse line.....	Easy	6.40	1 10	0.46	8.49	Average 9.93
Horse line.....	Steep.....	8.56	1 2½	0.30	11.37	

Paris, on easy lines, ten horses work one car per day, and do about twelve miles per diem; but with so large a car this number of horses would not suffice, if managers (with the view of showing a low cost per kilometer) did not relieve their horses, by giving them on an average less than half loads; that is to say run double the number of trips necessary. I consider that ten horses can readily work an omnibus with its load of twenty-six passengers, but ten horses cannot readily work a tram (grades, &c., being equal) with a load of more than thirty-five passengers. A six-ton tram engine can work a load of 100 passengers.

Roulement.—The system adopted in Paris of *roulement* is devised for obtaining uniform and comparative statistical results, no matter how irregular the service. Thus by the system of *roulement*, at the end of the month each engine and driver will have performed precisely the same mileage, he should also have expended the same fuel and oil; and the wear and tear of the machines, if carefully driven, should be precisely the same. All the conductors' receipts should also be of almost equal amount, and thus by comparison systematic dishonesty or neglect can be instantly detected. The bell-punch and uniform fares is the best control I have yet seen; but even that system requires public assistance to make it work satisfactorily.

Public.—All the public ask for are, quick through traffic, low fares, and a strictly-observed unvarying time table. Correspondence also is a public necessity, but too little understood in this country to be said to be a demand. By the establishment of suitable shelters, to the installation of which the public have as much right as cabmen, and of a miniature clearing house for settling accounts, a traveler could take a through ticket from one end of town to the other by the first public conveyance available, and change vehicles *en route*, if by so doing his journey might be more rapidly or more conveniently performed.

Colonel Beaumont, M.P., has pointed out that a steam tram-engine is obliged, both in steam capacity and in weight, to be used of the maximum type which starting on the stiffest gradient exacts; and that, consequently, we daily see a twenty horse-power engine called upon to do duty which three horses could perform, and which, on a level, the engine-driver and stoker could almost undertake unaided. This discrepancy and waste of power Colonel Beaumont attributes to the fuel being used locomotively; and, certainly, the mere horse-power required, if generated in a fixed engine, could be procured with about eighty per cent. less fuel. Colonel Beaumont, therefore, compresses air, and converts it into horse-power at about one-fifth the cost of steam; but as, in expanding the air again, he loses about seventy per cent. of the power stored, the actual gain is not more than ten per cent. Lamme's American fireless engine, besides the fatal inconvenience from loss by radiation, which renders every stoppage killing, is not economical in storing the power. Todd of Leith, seems to treat the question of exhaust in a very masterly manner, but I have no personal experience of his invention. Rowan, of Copenhagen, is the father of the combined car type; he has lately, however, gone in for a detached engine, the merits of which are kept secret. He claims for the former all the well-known advantages on a bad road of the bogie—of getting on the line easily again, also by means of steering the bogie—a strong break power, saving of dead weight, and a fan blast which does duty as an air-con-

denser. Brown, of Winterthur, whose latest engine I had the opportunity of examining in Paris, has in it produced a superior article. The machinery is raised five feet above the rail level, and the driving power is transmitted by vertical levers and coupling and connecting rods. The levers, being always in opposite directions, no counter weights are required. Hughes, of Loughborough, takes a prominent place, because he has shown he can do good work at a moderate figure, while his engines have been running fifteen hours daily, a most severe test. The following statistics of the Vale of Clyde tramways show that he worked at 5.61d. per mile, coke costing 24s. per ton, as against 48s. in Paris, and his engine requiring one man in lieu of two. The coke consumption was eight pounds per mile.

EXPENSES FOR SIX DAYS, OR 1800 MILES.

	£	s.	d.
Eight drivers, at £1 7s.	10	16	0
" " overtime fifteen hours.	0	8	4
Two cleaners, at £1 2s. 6d.	2	5	0
Waterman and coke carrier.	1	5	0
Lamp cleaner (boy).	0	10	0
Coke, 6¼ tons, at £1 4s.	7	16	0
Oil, suet and waste.	2	0	0
Water, 63,660 gallons, at 4d.	1	1	3
Salaries of manager, timekeeper, and office expenses.	5	10	6
	£31	12	1

REPAIRS.

Leading fitter.	1	12	0
Three fitters, at 30s.	4	10	0
Smith, job work.	0	10	0
Carpenter.	0	5	0
Materials, 12s. per engine.	3	0	0
	£9	17	0
Running expenses.	31	12	1
Repairs.	9	17	0
Interest and sinking fund, say 20 per cent., on £5000.	0	13	1
	£42	2	2

(£42 2s. 1d. ÷ 1800=5.61d.)

Messrs. Merryweather, the well-known fire-engine makers, have had more engines running than any other maker, having turned out about fifty. The earlier makes, however, were far too small, and required such constant attention as to have been provocative of many collisions, owing to the driver having multifarious duties to perform, which interfered with a sharp look-out. In Paris no condensing or speed-checking apparatus was required by the authorities, so they were not supplied. Their Cassell engines were far superior, and have, it is said, been eminently successful. Messrs. Fox, Walker & Co., through being last in the field, have profited by all the experience gained by fifteen months' constant work in Paris. They are supplying the French Traction Companies of Paris and Rouen, and their engines, for workmanship, economical working, and skillfully-met conditions leave little to be desired. The object of this paper is to stimulate discussion on the whole subject.

Mr. J. Scott Russell, F.R.S., said they must all be much obliged to Mr. Haddan for the information he had given from his practical experience, which was especially valuable at the present moment. He had seen the engines of Mr. Hughes in Scotland, and Messrs. Merryweather's elsewhere, and had always considered that there was great promise in them; and he had no doubt that if the mechanical engineers of this country really set about the task, they would be able to create the very engines that were wanted in a perfectly satisfactory manner. He knew well what the difficulties were from his own experience of engines, for he had had the same class of difficulties to grapple with. It was quite correct to say that much larger bearing surfaces were required in such engines than in locomotives, and many adjustments which were not there called for. He also agreed with Mr. Haddan as to the extreme weakness of crank axles generally, but, of course, with a little experience, they would learn how to make them strong enough. Still they would not be wise things to use where concussions were constantly taking place in every possible direction. The great question appeared to him to be this, was the separate engine or the engine combined with the carriage the better of the two? He thought there were circumstances as to exceptional gradients and other things, which in one instance would go in favor of the combined engine, and in different circumstances would go in favor of the detached. At present his impression was that a steam locomotive engine, both for economy and management of stock generally, should be a separate carriage, however

it might be made to appear outside as though it were a part of the other carriage; and that on the other hand, where you determined on the combined system, you ought to abandon steam and take condensed air or some such motor as the propelling power. His opinion, therefore, was against applying the steam-engine in the car itself, and in favor of using it separately, and in favor also, in certain circumstances, where you could conveniently do it, of having stationary reservoirs of power at which you could fill the reservoir of the carriage with condensed air and use it as an economical and convenient propelling power. It was obvious that a large carriage with a couple of boilers in it was, to say the least, not very nice company to travel in. The great thing to be done with the detached engine was to make it more durable, and the only way in which this could be done was to more perfectly detach the propelling power from the propelling axle, so that all the mechanism of the engine should be relieved of the shocks upon the wheel. In no engines he had yet seen had that been perfectly done. This paper would contribute materially to assist engineers in meeting the various difficulties which had been quoted; and he hoped the mechanical engineers of England would now devote their attention to this subject, and that the public generally would thoroughly take up the tramway question. It was the great supplement to the railway question, and his opinion was that, instead of extending railways by small branches all over the country, it was now desirable that from every railway station should proceed, in all directions, a well-organized system of tramways. He would advise engineers to keep their locomotives out of Cheapside for the present, and rather to apply them in suburbs, where they would form a great public convenience to many, and would inconvenience but very few.

Mr. Matthison said, that the profession had had but little to do with the grooved rail, which had been forced upon them by the authorities. In the United States, where they had more scope, they did not use them. In the interest of people who rode in carriages, there was no doubt the grooved rail was good, but for the tramway company the flat rail was much preferable, and when the question of steam-engines came up it was of still more importance, because much of the difficulties of the steam-car had arisen from badly laid rails, which at the best had been made only for horse-cars. Discussion as to steam-cars was useless until the best form of tramway had been decided upon. The point mentioned by Mr. Scott Russell of detaching the mechanism of the engine from the jolting of the road had been very successfully accomplished by Messrs. Kitson, of Leeds. There the action of the steam-engine was applied to a central axle, from which the power was taken to the wheels, thus saving the gear from the jolts of the carriage.

Mr. Kincaid said, Mr. Haddan had laid down certain hard-and-fast rules, which it would be difficult for civil engineers to follow in practice, because there was hardly a case which came under their notice in which they did not find very different circumstances. For instance, the grooved rail was an absolute necessity in crowded towns where there was much carriage traffic, but it was not so in America, where this kind of traffic was comparatively small. No doubt the grooved rail with a fillet gave much more work to the engine than one without, and in many of the future lines, to which Mr. Scott Russell had alluded, it need not be insisted on, and a modification of the ordinary railroad might be adopted on which the traffic could be carried much more easily. He did not quite follow the table of receipts and expenditure, and it seemed to him that the working expenses were put very low—much lower than he had seen worked out anywhere else. As a rule the expenses were a great deal more than fifty per cent. of the receipts, and he was not aware that the Paris tramways were worked at so much smaller a percentage. The only experience they had had of the control of the Board of Trade in this matter had been in Glasgow, and from the report just issued by General Hutchinson he came to the conclusion that the Board had well considered the matter, and were working out the general ideas of the committee alluded to by the chairman.

Mr. J. Stables had had some little to

do with the construction of the steam-engine patented by Mr. Brunton for the combined car used on the Wantage branch line, which answered very well. The requirements of the committee, to which reference had been made, were very difficult to meet. They required the car to stop immediately, and not to exceed a certain rate per mile, and several patents had been taken out to effect this latter point mechanically. Mr. Stables said it was quite plain the report of the committee, if adopted, would place some difficulties in the way of construction, and he believed that this was the reason that the matter had not been more attended to by mechanical engineers, because they felt sure that some time must elapse before the engines would be required. The public required a car which made no noise or smoke, and which could be stopped at any moment, to run upon a rail level with the street, and not to interfere in any way with carriage wheels. In New York the rails stood above the surface, and were almost as strong as those of a railway, and engineers had no difficulty in making engines which would run well upon them. The present rails required a very light engine to run upon them; thus it was found that the resistance was much greater than was anticipated, and therefore the cylinder area had to be made larger and the machines heavier. The cylinders in Messrs. Fox, Walker & Co.'s engines were placed high up above the boiler, but unless they were in the center of the engine there would be great oscillation, especially if there were two cylinders. He would suggest the cylinder ought to be in the line of pull and thrust, so as not to interfere with the springs. Again, the axles and bearings should be made like the old mail-coach axles, with leather washers and oil boxes, and every part should be well covered and protected from dust, which was the great cause of repairs being needed.

Mr. Rowan (Copenhagen) said, it was quite true that the late Mr. Grantham made a combined car before he did, though he had previously taken out a patent. He might venture to give the result of his experience, because it was gathered from different sources abroad, and he had no interest or prejudice in favor of one maker more than another; he simply wished to get the best engine and the best system. Although he was not entitled in any way to be called the father of the combined car system, he was quite prepared to take the responsibility of it. The trials he had made since he had ridden on Mr. Grantham's had convinced him more and more that the combined car would carry the day over the detached engine. Without entering into the question of whether compressed air or steam was the best, he thought that whatever engine was the best for the one would be decidedly the best for the other. There was a new field now open to the mechanical engineer, viz., to make a light engine. No one had tried in connection with railways to make a light locomotive, because there you must have weight to drive the engine, but in the combined car, if you could make an engine sufficiently powerful which weighed only 100 lbs., you could take it up any gradient, because half the weight of the load would always be on the driving wheel. He believed that if mechanical engineers had their attention directed to this point they could make engines strong and solid, and yet infinitely lighter than 5½ or 6 tons. Mr. Haddan laid great stress on the point that the engine and car combined would necessitate the engine going to the repairing shop and the car with it, but that was by no means the case with a car of the type he had been experimenting with, and he had seen the results of over a thousand miles run, under the direction of the Prussian Government. The engine could be detached from the car in two or three minutes, and any engine could be used with any car, although you got the full advantage of using the weight of the load to go up hills; and he laid great stress on that fact, because if you wanted to make cheap new lines to serve the railroads, you must expect to encounter sharp curves and steep gradients. He believed Messrs. Kitson's engine was the best which had yet been devised, being much lighter, but with great power, having 28-inch cylinders, with a 15-inch stroke. They also had the advantage of being entirely boxed in from mud and dirt, and every part was under the driver's eye and control, and he could clean up

while waiting and stopping. Still, he hoped before long, they would see an improvement even upon that.

The Chairman, in proposing a vote of thanks to Mr. Haddan, said he did not think an outside cylinder would get over the difficulty of crank axles, because if you connected the leading and driving wheels it must be by means of a crank axle, so that, whether the cylinders were inside or outside, you must have a crank axle, unless you adopted the system of Messrs. Kitson. Mr. Scott Russell had endorsed what he believed was the correct principle, in laying down that if you had steam you must have a separate engine, because the inconveniences of steam were such that you could not have a steam-engine side by side with the passengers. His name had been mentioned in the paper in connection with an air-engine, and one of the advantages of that system was that it got over the difficulty, inherent in steam, of combining the engine and car together. He might express a hope that, on some future occasion, he might have an opportunity of reading a paper, and explaining what he had done in that direction; and he believed there was every probability of such an engine occupying, with success, the field alluded to by Mr. Scott Russell. It was extremely desirable to have some means by which you could limit the speed on tramways, but when the committee came to consider the great difficulties that were in the way of providing any mechanical and self-acting regulator, they dismissed it as being impracticable. It appeared to him that what mechanical engineers had to attend to was the absolute production of an engine which would fulfill the requirements laid down by the committee, and which would not run only two or three days together when committees and engineers came to see it, but should bear the test of continual working, and should have earned its money when it came to the end of its six months, and paid its working expenses. When that was done, it would be a great stride towards the extension of the power of locomotion in this country, namely, the extension of tramways. Railways formed the main arteries of communication, but it remained for tramways to complete the communication with villages and other places which could not otherwise be reached.

STEEL PLATES.

From "Engineering."

It is universally allowed that steel plates made from a metal in a state of fusion, cast into an ingot and then hammered and rolled, are much more likely to be mechanically homogeneous than iron plates made up of a number of pieces welded together by hammering and rolling. We use the term homogeneous in the sense in which it is usually employed when speaking of the difference of structure in steel and wrought iron. To the soundness or homogeneousness of steel plates is due the freedom from lamination and blisters, the more equal tenacity and ductility lengthwise and crosswise, their bearing cold flanging and bending so well in all directions, their standing being solid drawn like copper or lead, and the severe cold punch test they are able to bear, compared with best Yorkshire plates. Homogeneity, however, does not mean absolute uniformity of structure. In a homogeneous steel plate, we may find different degrees of ductility and hardness, by which differences in structure are implied. The homogeneity of steel plates is almost universally regarded as an unconditional advantage. With this general opinion we do not, however, entirely agree, and it appears to us that its unchallenged acceptance has frequently led to many of the cases of disappointment occasioned by the failure of steel plates, and their being now considered untrustworthy by many of those who have tried to use them.

A sound strip of very inferior and brittle iron plate, having the tenacity of say, 21 tons and 18 tons respectively

along and across the fibre, and a ductility of 3.5 and 1.5 per cent. respectively in 8 inches may be broken by a single blow with a hammer. A sound strip of steel plate of the same dimensions having a tenacity of 36 tons and an elongation of 10 per cent., will resist a much severer blow, or a number of equally severe blows oft repeated. Should, however, the strips have a very slight fracture at the part affected by the blows, either at the sides or edges, such for instance as might be caused by the careless use of shears in bad order, the conditions of comparative resistance may be completely altered. A number of light blows may now break the steel strip, which will not injure the iron plate. By being in a state of tension the tendency of the steel strip to break before the other will be further increased. The flaw or incipient fracture, which will scarcely affect the strength of the iron, may seriously affect the strength of the steel. By a slight accident of finish, what would naturally be considered the tougher and stronger, may actually become the more brittle and less trustworthy material. This appears to be the explanation of what has frequently taken place and been ascribed to capriciousness on the part of the material. The hammering of a hard plate with a roughly-dressed or undressed edge may cause an incipient fracture in a plate. When this plate is placed in the shell of a boiler tested to 10 tons or 12 tons per square inch, or in the firebox of a locomotive, and exposed to varying strains due to changes in the pressure and temperature, these incipient fractures pass, sometimes suddenly, into the body of the plate, often avoiding the rivet holes in what has been called a mysterious manner. This apparent caprice is doubtless due in a great measure to the homogeneousness of the material.

When the plate has not suffered from tempering, the resistance of the material is practically uniform and the fracture tends to pass in a straight line, being readily extended by jarring or vibrations. In an iron plate, owing to the want of homogeneity, and the unequal resistance at different points of the material, the fracture often takes such a direction that it is not affected by jarring even when the plate is strained, and allows the stress to spring the plate, without tending to increase the fracture, which is tantamount to having the ductility of the material increased indefinitely. This is especially the case where the iron plate is stretched in the direction of its fibre.

The possible advantage of a want of homogeneity may be roughly illustrated by the well known expedient of arresting the progress of a fracture in an iron, by drilling a hole at the end of the fracture and inserting a rivet. The want of homogeneity tends to arrest the progress of a fracture along or across an iron plate, as lamination arrests the progress through the whole thickness of a plate of a fracture on one side, the starting of which in the first instance may have been indirectly due to the presence of the lamination. Apart from the advantage a stranded wire rope possesses for coiling and uncoiling compared with a solid rod of similar thickness, there is an element of strength imparted by the mere fact that the severing of one strand does not impair the efficiency of the remainder, and this is very important in many situations and purposes to which copper, steel, and iron ropes are applied.

Where there is a tendency for the stresses to gradually work open the material, as at the root of a flange in the furnace tube of a Cornish boiler, and where there is no injurious chemical action of the water, a tough steel flange will resist fracturing longer than an iron one, but when the fracture has once been started, the structure of the steel tends to make it go much more quickly.

We have in the above inquiry suggested the quality, viz., *ductility*, that is wanted in order to counteract that which tends to make the homogeneity of steel a positive drawback, causing the material to give way without warning. In the few works where steel plates, having about the same ductility as ordinary iron plates, are skillfully treated, such plates can be successfully used, But for the general run of boiler-makers and shipbuilders, a greater ductility is necessary for the successful use of steel than is required for iron plates.

Accurate knowledge on this branch of the strength of materials is still wanting. It is, however, probable that the

stronger and less ductile the steel, the greater will be its resistance to the starting of a fracture, but when a fracture has once been started the greater the ductility, and consequently the less the tensile strength, the more suitable the material for resisting the further progress of the fracture, especially where there are jarring strains or strains of varying intensity, and where the material is in a state of tension. In all cases where the strain is unequally distributed, as at the overlap of plates in tension, the greater the ductility the more uniformly will it allow the strain to be distributed over the section.

The soundness of steel plates is not quite so general as is often taken for granted. The blow-holes or honey-combing commonly found in the ingots are certainly not always removed by the subsequent hammering and rolling of the material. Some steel manufacturers affirm that the metal separated by the bubbles of air or gas cannot be welded together by the work done upon the material in the ordinary process of making it into plates. Others maintain that the metal round the holes in the body of the casting, which is clean, does become welded together, whilst the metal round the blow-holes which has a film of oxide on it, can never be welded by any amount of subsequent hammering and rolling. Where the metal round these blow-holes does not get welded together the holes become flattened out in hammering and drawn out in rolling. They sometimes appear as streaks or lines on the surface of the plates, and these lines cannot, in many cases, be regarded otherwise than as incipient fractures the spreading of which, the structure of the rest of the material, especially if at all hard, is so badly designed to resist. We have here another reason for getting as ductile a steel as possible.

It, however, unfortunately happens that the softer and more ductile the material, the more spongy and honey-combed it is likely to be. We have then until lately been in this dilemma, that the greater the ductility we succeeded in obtaining, the greater was the risk we ran of having plates unsound, thus incurring the very fault we require the ductility to withstand. One way of getting out of this difficulty was shown by Mr. Bessemer long ago, this plan being to compress the steel whilst in a state of fusion. Subsequently this plan of compressing fluid steel was carried out by Messrs. Révollier, Biétrix & Co., in France, and later still at the Neuberg Steel Works, in Austria, while in this country Sir Joseph Whitworth has carried out this mode of treatment for years and has developed it most successfully for certain purposes. Considering the nature of the plant required, however, there appears to be little chance of this system of working being adopted for the commercial production of blooms for the manufacture of steel plates, and hence recourse must be had to other modes of obtaining soundness. That a vast advance in this direction has been made in the past two or three years no one who has watched the progress of our steel manufacture can possibly doubt, the employment of ferro-manganese having been attended with most important results as regards the production of mild steels. There is also no doubt whatever that our steel manufacturers are fully alive to the importance of ductility in the plates they produce, and the leading firms are and have been for some time past turning out material which is very satisfactory in this respect. At the same time this material requires proper treatment, and it is with a view of promoting this treatment that we have in the foregoing article dwelt upon the influence which the homogeneity of steel plates appears to us to exert on the power of such plates to resist incipient fractures.

At a recent meeting of the French Academy of Sciences a paper was read giving an account of the working of a very successful ventilating apparatus lately fitted on board the French transport Annamite, one of four large vessels built for conveying troops to and from Cochin China. The ventilation of the ship is effected by utilizing the heat escaping up the funnels when the vessel is under steam; or by lighting small fires for the purpose when the transport is lying at anchor; and especial attention has been given to providing for the ventilation of a sick bay established in the center of the vessel, and also of the deck on which the men sleep.

THE WORK OF THE EARLY STONEMASON.

From "The Builder."

PROGRESSIVE development of the art of the mason forms the subject of a special chapter in the history of architecture. It is a chapter of no small importance; as its study will be found to extend to the earliest dates of human history, if not into pre-historic times. The facts on which any theory must be constructed are durable realities. And the special value of the investigation consists, not only in the fact that it endeavors to fill up a gap in the history of architecture, both as a science and as an art; but that it further tends to link architectural with ethnological progress, and to exhibit those steps in the history of various races which have been parallel in the order of national development, although not in actual time.

The subject has especial interest, as tending to throw some light on the noble pre-historic relics of our own island, as to which there is so entire a break with regard to any traditions of their origin. We do not forget the efforts that have been made to bring down this origin to the recent date of the Roman occupation of Britain. Without, at the moment, insisting on the weighty arguments opposed to this view, for some of which we may refer to our own columns, we think that it cannot be denied that to trace the development of the art of the stone-cutter is a method of research which cannot fail to throw some light on the question.

Masonry, as the term is now ordinarily employed, may be taken implicitly to include the idea of stone-cutting, as well as that of the use of cement, or some artificial method of joining stones solidly together into a mass. But the definition given in the last edition of Johnson's Dictionary is "craft or performance of a mason." And a mason is simply defined as "a builder in stone." These terms cannot be bettered; for they include not only the most finished effort of a perfected art, but the rudest steps of its commencement. Such was the work to which we recently called attention at Tiryns, where vast unshapen stones are piled and fitted into walls, "with only occasional, and apparently later, marks of the tool."

It has, perhaps, escaped attention hitherto, that between the first stage of Cyclopean, or primitive stonework, and the second stage,—in which, while the idea of the course of masonry is undeveloped, the sides of the several stones have been reduced to plane, though rarely vertical joints,—has intervened a step in human progress which is not due directly to the mason. We are apt to look at the succession in question as if it were the simple development of masonic skill. But we have no reason for assuming that the builder of Tiryns was unaware that it would have been better to dress his joints than to pile stone upon stone, fitted as best he could. Something was required beyond the wish to make the strongest wall possible. That something was a tool that would cut stone.

As to this, it is perhaps safer to put our views in a tentative form than to attempt to speak with a preciseness as yet unjustified. What was the first tool of the stone-cutter? How far was it possible to cut stone with stone tools; to dress joints by the use of axes of obsidian, jade, or any hard stone? The subject is worth a little experimental research. Supposing it to be shown that such a commencement of stone-cutting was a possible step in the art of the mason, we think that a certain distinction may by this means possibly be pointed out in the examination of ancient masonry. For while a stone axe might, we apprehend, occasionally be used, especially in the case of tufa, and of not a few descriptions of less compact rock, we are not prepared to admit the applicability of a chisel made of stone. If this be so, we shall find in the transition from axe-dressed to chisel-dressed stone a note of time which indicates at what period in his progress the mason was first indebted to the contemporary skill of other artisans for metal tools.

This brings us to another question, of no small importance, if thoroughly solved. To what extent was it possible

to cut stone with a chisel before the introduction of iron? We are aware from literary testimony that the manufacture of iron dates much later than that of bronze. Not that the subject has been exhaustively treated; but still iron, when it first came into use, appears to have been the rarer and more highly valued metal. In Homeric times (whenever they date) bronze or brass was used not only for defensive, but for offensive arms. The earliest date to which we can with certainty carry back the proof of the use of iron is 5,400 years ago. In the Pyramid of Souphis (or Cheops) iron has been found in such a position as to leave no doubt that it had been in the possession of the builders of the pyramid, under the fourth dynasty of Memphite kings of Egypt. This significant discovery may perhaps throw light on another question of extreme importance as regards the history of masonry. That is,—how were the hieroglyphics cut? We shall be indebted to those learned men who are doing so much to unveil the written mysteries of Egyptian history for any definite statement of the date of the most ancient incised hieroglyphics; and also, as to the fact whether any appreciable differences in the style or mode of cutting is to be detected, and referred to known dates. The general impression produced by a study of the inscribed statues and *steloe* at the Turin Museum, at the British Museum, and elsewhere, is, that as far back as Egyptian relics exist, the hieroglyphics were cut in basalt, green-stone, granite, or other hard stones, with a depth and a precision which are those of the gem-cutter rather than of the stonecutter. As iron was known in the time of the fourth dynasty, steel might have been also known; or the use of iron of meteoric origin, or of extreme purity, may have given to the early inscribers the means of effecting their work. On the other hand, there is the possibility that some kind of drill was used for the inscriptions; and if corundum powder was employed, a soft iron or copper drill might have been sufficient for the purpose of the workman. Adamantine corundum, an excessively hard spar, occurs among the granite and mica schists of Egypt. Granular corundum, or emery powder is found in Greece, and may very probably have been known to the early Egyptian artists. At all events, this part of the subject will repay research. At present we will only attempt to lay down the principle, that the mode of cutting stone that was employed at any particular period affords an index to the knowledge and use of metal tools possessed by the masons of that time and country.

In Mycenæ we have instances of the cutting of stones of the magnificent dimensions of nearly thirty feet by eighteen feet by four feet. At Avebury we have stones, presumably once cut, of almost equal size. In the Great Pyramid we have examples of enormous stones cut so that the joints are impenetrable to a knife-blade. In the walls of the Haram or Temple enclosure of Jerusalem we have stones of the same giant family, some of which are not older than the time of Herod the Great, or the commencement of the Christian era. We have thus a range of certainly 3,500 years, during which the masons of Greece, of Egypt, of Syria, and possibly those of Wiltshire, cut, dressed, and set enormous stones. To how much earlier a date we may hereafter be able to push back the commencement of the art of stonecutting, which we think may be fairly associated with the presence of polygonal cut stones in a wall, we cannot attempt even to guess; but we have, at all events, something like a means of measuring the relative advance of various tribes or nations by the comparison of their works. Whether the builder of the Great Pyramid wrought 1,000 or more years before or after the builder of the walls of Tiryns, the former was certainly a much more educated and experienced mason than the latter. So again, by comparison of their works, we should conclude that the masons who built Stonehenge and Avebury were much earlier, dating by their professional knowledge, than those who built the Pyramid. Civilization, we know, has often been narrowly localised. A high state of industrial perfection in one country may co-exist with a low condition in another at no very remote distance. If this were not the case we should have something approaching to the nature of proof that Stonehenge is older than the Great Pyramid. We are

unaware of any good data for fixing the earliest possible period of the erection of the English megalithic temples, though reasons have been adduced in this journal for the opinion that marked geological changes have affected this part of Europe since those noble structures were completed.

Another very ancient evidence of the art of the stone-cutter is to be found in excavations of rock. Of these the examples in Egypt, in Eastern Syria, in Western India, and elsewhere, are not unfamiliar to the architect. Very generally they give signs of being of much later date than the megalithic buildings of which we have been speaking. A trabeate form of architecture has been imitated, in numerous instances, by men who wrought in the living rock. But there are two groups of stonework *in situ* as to which we are as yet only in course of receiving definite information. These are the military rock defences of Palestine, and the rock-cut tombs which abound in the Holy Land. The old sites of the Jewish cities are for the most part covered with mounds of rubbish, in which it is utterly vain to expect such surprising relics to be hidden as have rewarded the explorers of Mesopotamia. But very often the modern towns which bear the names, and no doubt stand on the sites, of Biblical and pre-Biblical cities, are surrounded by a scarp of rock artificially cut. "The most wonderful of these scarps," writes Lieutenant Conder, R.E., in the Quarterly Statement of the Palestine Exploration Fund for January, 1878, "is that at the south-west corner of Jerusalem, where a carefully-worked wall of rock, fifty feet high, is traced for over 150 yards. Similar scarps, on a smaller scale, are not uncommon throughout the country." The account given in the Book of Samuel, of the capture of Jerusalem by David, 2,900 years ago, gives reason for the belief that the rock scarp was at that time in existence, even if it may have been carried to a greater depth later; as to which, however, there is no evidence.

The same explorer calls attention to another work of the stone-cutter in the same country; namely, the excavation of rock-cut reservoirs and cisterns. "Bell-mouthed cisterns occur so constantly near, and in connection with, Jewish tombs, that it seems natural to ascribe them to Jewish workmen, though they have no marks of date which will fix them so early." It is, however, evident that works of this nature must have been co-eval with the settlement of many parts of the district bordering on the Mediterranean. Those tribes which inhabited watered plains, or dwelt on pervious soils, in which they might find springs, or dig wells, had no need of the services of the quarrymen and the mason in combination. But where the soil is rocky and impervious to water, where the rainfall is unequally distributed throughout the year, and where the temperature renders a certain abundance of water a necessity of life, no permanent habitation of a country can be effected without the construction of cisterns.

Of like nature to the Syrian cisterns are the granaries or treasuries that are sunk in the soft, dry rock so prevalent along the Eastern versant of the Apennines. In the neighborhood of Foggia, where rich crops of corn are secured in the summer months, the ground is, in some places, honeycombed with bell-shaped or conical excavations, in which corn is stored sometimes for many years. The form of those granaries so closely resembles that of the Etruscan tombs, in which the arch is anticipated by the progressive over-setting of course above course of small bedded and squared masonry,—set, in some tombs that we have opened, without mortar,—that it seems proper to associate the excavating with the building stone-cutters of *Magna Grecia*, and probably of other countries.

With regard to tombs, the explorations of Lieutenant Conder throw light on a very important mark of relative antiquity. Near to every modern village or ancient site of a town in Palestine, usually on some opposite hill, are to be found rock-cut tombs. They are hardly ever found within the ruins. They may be divided into three classes. Of these, the first bear the name of *kokim* or oven-like tombs. They are formed by cutting small parallel tunnels, each of the dimensions proper to contain a human body, from the sides of a rectangular chamber. The *kokim* vary in number from one or two up to eighteen or twenty; and in size from the length of three feet to that of seven feet. There is no system of

orientation. The entrance-door to the chamber is in the face of the cliff, and the chamber itself is excavated in accordance with the lie of the rock. The chamber may probably be regarded as the original provision for a family tomb; fresh *kokim* being cut from time to time, as wanted, of dimensions not larger than requisite for the sepulture of the individual for whom it was cut.

The proof that this form of tomb is the oldest in the country is definite. The second class of tombs is that containing *loculi*, or side receptacles, parallel with the walls of the chamber, instead of being at right angles to it as in the former class of tombs. The *loculus* arrangement is still adopted in mausoleums in Italy, as for instance, in the Superga, near Turin, where the members of the Royal family of Savoy are laid to rest in parallel niches, something like the berths in a vessel, the faces of which are walled up on the interment being made. That these tombs in Palestine are of later date than the *kokim* is shown by the fact that there are instances in which an outer chamber, containing the former kind of receptacles, leads to an inner chamber,—pierced further in the rock,—containing *loculi*. But no instance has been found in which the order is reversed.

Of the anterior limit of the date of the *kokim* tombs it can only be suggested that it may probably have been as early as the inhabitation of Palestine by a burying, as contrasted with a burning, race. That they were used by the Jews is shown by the description given in the Talmud, and by the occurrence of Hebrew inscriptions, and of a representation of the sacred candelabrum in certain cases. To others a traditional veneration is attached. But the substitution (in part or in whole) of the second for the first method of construction is shown to be older than the Herodian time by the references made by each of the Evangelists to the rolling stone with which the mouth of the tomb in the garden was closed. This arrangement is said by Lieut. Conder to occur almost invariably in the *loculus*, but not in the *kokim* tomb. An inclined groove is cut before the entrance to the chamber, and a cylindrical stone, like a mill-stone, is placed in the groove. To enter the tomb it is necessary not only to roll the stone up the slope, but to wedge it up, as it would otherwise descend with its own weight, and completely close the entrance.

The tombs belonging to the second group are more ornamented than those of the earlier system. Some of them have façades covered with a rude kind of imitation of Classic mouldings. "There is generally a portico, with a frieze above, supported by pillars cut in the rock, with Ionic or Corinthian capitals. The chamber is sometimes also ornamented within." If the attribution of a well-known tomb at Jerusalem to Helena, Queen of Adiabene, be correct, we have a dated instance of this kind of tomb in the first century of the Christian era, in accordance with the references to the rolling stone made by the Evangelists. The *loculus* tombs occur during the Byzantine period, but are not found in the crusading cemetries.

The third class of tomb is the rock-sunk tomb, which is a shaft sunk in the rock, with an arched recess on either side, in which two bodies can be deposited. The earliest examples found by Lieut. Conder are connected with Byzantine monasteries. No indication has been found of the use of this kind of tomb by the Jews, unless it be taken from the account of the tomb of Lazarus, in the fourth Gospel, which is called a *spelæum*, with a stone that lay on it. The natives of Syria call this third group Frankish tombs.

The only relic of Jewish architecture further mentioned by Lieut. Conder (omitting for the present any question as to the sites of the high sanctuaries at Jerusalem and at Hebron), are the vineyard towers. "These buildings are generally about fifteen feet square outside, and the same in height. The walls are of unhewn blocks, four feet or five feet long; the roof, supported on a buttress, is of slabs seven feet or eight feet long. These solid and rude buildings occur near rock-cut wine-presses and ancient tombs."

The Great Works of Herod the Great at Cesarea, Samaria, Ascalon, Antipatris, Jerusalem, and Herodium have almost entirely disappeared. It is only at Jerusalem and Hebron that megalithic masonry, with the draft and dressing of

the stones which are peculiar to Palestine, now occurs. The aqueducts attributed to the same period are of small masonry laid in excellent mortar. Exact information as to all these architectural points will be accessible when the memoir, now in course of preparation to accompany the Ordnance map of Palestine, is published. That work will be found to contain a perfect mine of information for the architect. Plans have been made of all ruins of any importance. The size and mode of dressing of the masonry has always been noted, with the character of the mortar, and other particulars. Mouldings of capitals, cornices, and bases have been measured, and sketches made of tracery. Photographs of architectural details have in many instances been taken.

The peculiar drafting of the enormous blocks forming the walls of the High Sanctuary at Jerusalem is known to most of those interested in the subject, from photographs. We must await the early publication of "Tent Work in Palestine," announced by Mr. Bentley, for more full description of this unique, or almost unique, masonry, and for a statement of the evidence as to its anterior and posterior dates. There is also a drafted masonry of the Byzantine epoch, between A.D. 326 and A.D. 636, during which period Palestine was covered with Byzantine monasteries and chapels. Of this there is a dated example in the walls of the fortress built by Justinian round Zeno's Church on Mount Gerizim. The masonry is, however, entirely different from that at Jerusalem. The draft is deeper and broader, irregularly cut, and finished with an entirely different dressing. Semi-circular arches accompany this masonry, with narrow key-stones, and broad voussoirs at the haunches. This is also the case with the tunnel vaulting of the churches, as in that of St. John at Beit Jibrin. Another peculiarity of this age of building is the use of a large and heavy lintel, generally marked with a cross, and almost invariably present over a doorway; although the weight is very usually taken off by a relieving arch above. In some cases these enormous stones are the only relics that remain to tell of the site of a former building. Sometimes these lintels were inscribed. At Khoreisa the surveying party found one bearing the Greek text, "This is the gate of the Lord."

The crusading epoch in the greater part of Palestine, as far as building is concerned, extends from the building of Toron (now Tibrin) in 1104, to that of the church at Nazareth in 1187. On the coast, however, there are later structures of Christian origin; the restoration of Cesarea dating in 1251. In the Eastern Crusading buildings, one of which is the hospital at Jerusalem, we find heavy mouldings and semi-circular arches. In the Convent of St. Marie la Grande the arches are slightly pointed, and there is a dog-tooth moulding resembling those common in English churches. At Samaria the round arch has been used as late as the latter half of the twelfth century. At Beit Jibrin, the remains of the Church of St. Gabriel, built about 1134 A.D., have slightly pointed arches, rising from heavy pillars and cornice. Imitations of Corinthian capitals occur in most of the earlier Crusading churches; and from the fact of their exact similarity to one another in the same church it is inferred that they were the work of the twelfth century masons, and not the spoil of earlier buildings.

Growing later, the architecture becomes more light; beautiful clustered columns replace heavy pillars, and ribbed groining is introduced. The arches are always pointed, with distinct voussoirs. The Corinthian capitals are succeeded by others of an endless variety of form, leaves, varying from smooth to deeply serrated, being the usual ornament.

Diagonal dressing is one characteristic of Crusading work. At least, this mode of finish is not found at an earlier date. It was not always employed, however, by the twelfth-century builders. A rough kind of diagonal dressing is also found on Saracenic work, but it is possible to distinguish the two. The use of the toothed chisel prevailed, as was the case at the same date in France and in England. Masons' marks, including every letter of the alphabet except D, G, Q, and X, also abound in this work, as well as inscriptions. A collection of masons' marks is given in the Memoir. The exterior walls of Crusading fortresses are of massive ashlar. They are almost invariably drafted, with a rustic boss, which projects sometimes a foot from

the draft. This work is perfectly distinct from both the Jewish and the Byzantine drafted masonry.

The Saracenic work is known by its small and less finely cut masonry, by the absence of masons' marks, by the pointed arches, and by the low relief of the ornamental designs. There can be no doubt that the publication of the Memoir to the Map of Palestine will be a very valuable contribution to the history of the craft of the mason.

ON STRAIN AND FRACTURE IN BARS OF VARIOUS MATERIALS.

By Mr. W. J. MILLAR, C. E.

From "Iron."

In a former paper upon "Strength and Fracture of Cast Iron," the author pointed out the connection between the form of fracture and the position of fracture in cast-iron rectangular bars when exposed to a breaking weight at the middle of span. In the discussion upon that paper, Professor James Thomson brought forward some interesting facts regarding fractures in other materials, and instanced certain substances, the forms of fracture in which would repay further investigation. Some remarks were also made on supposed connection between the forms of fracture and the neutral layer existing in the bar undergoing strain, and it is more in reference to this latter question with which the present paper has to deal. The author has made several experiments with bars of sealing wax and glass, and the following results have been obtained. Ordinary sticks of sealing wax were placed so as to rest at or near their ends, and were then loaded in the middle; the loads were gradually increased until fracture took place. The fractures so obtained were curved and removed from the center, and these curved or horned fractures pointed towards the center of span, or point of application of the load. Several bars of plate-glass were tested in the same manner, and broke with fractures having forms and directions similar to those of the sealing-wax bars. In these respects the bars of wax and of glass behaved similarly to the cast iron bars described previously. To determine the position of the neutral layer in cast-iron test-bars experimentally presents considerable difficulty, owing to the small amount of deflection, and consequent slight change of figure, no change having been observed upon the dimensions of bars tried in this way, although measurements were taken to $\frac{1}{1000}$ of an inch.

At first sight it may seem probable that since cast iron is about six times stronger in compression than in tension, that, therefore, the neutral layer would lie much nearer the compressed than the stretched side. The views of the best authorities on this subject are in favor of the position of the neutral layer being in the center of gravity of the section, which, in a rectangular bar, would be at the middle of the depth of the bar.

The object of the present paper is mainly to show that from experiments which have been made upon glass bars, we may infer the position of the neutral layer in cast iron bars. It has been found, when a bar of glass is subjected to strain and submitted to the action of polarized light, that the neutral layer can be seen, and that it lies midway between the two sides of the bar. Mr. Spottiswoode, in a lecture delivered on "Polarized Light," in 1873, says, speaking of a bar undergoing bending:—"The side towards which it may be supposed to be bent is, of course, compressed while the opposite is stretched out. Between these two there must be an intermediate band, more or less midway between the two, which is neither compressed nor stretched. The moment the strain is put upon the bar, light will be seen to pass through the parts of the bar nearest to both sides, while a band remains dark midway between the two."

An illustration of this was given by Mr. Spottiswoode at his lecture on "Polarized Light," Glasgow Science Lectures, 1877. A description of similar experiments will be found in the Transactions of the American Society of Civil Engineers, vol. iii.

Now it appears, from experiments by Messrs. Fairbairn and Tate, that the resistance of glass to compression is about twelve times its resistance to extension, so that if we were to argue from the ratio of these strengths as to the position of the neutral layer, we might expect to find the neutral layer very close to the compressed side; the experiments, however, with polarized light, conclusively show that the neutral layer is midway between the compressed and extended sides. Again, since curved forms of fracture are found to occur in glass bars whose neutral layer is situated as described, it appears that the form of fracture in these bars gives no indication of the position of the neutral layer, but that they simply indicate, as in the case of cast iron bars, the position at which the fracture has commenced, viz., removed from the center of span. We may, therefore, fairly argue that the neutral layer in cast iron bars lies midway between the compressed and extended sides.

The author had been unable to find from already recorded experiments the relative strengths in tension and compression of sealing wax, but from an experiment made with a view to determine this, it appears that the tensile strength of sealing wax is about 210 lbs. per square inch, whilst the compressive strength is over 1,500 lbs. per square inch. From the foregoing experiments it appears that the modulus of rupture of plate glass is about 7,400 lbs. per square inch, and that the modulus of rupture of sealing wax is 1,370 lbs. per square inch. The average breaking strength of the 81 cast iron bars formerly described was 3,571 lbs., from which it appears that the modulus of rupture is 48,000 lbs. per square inch. The various moduli of rupture are calculated by equating the bending moment and the moment of resistance.

$$\frac{W \times S}{4} = \frac{R \times B \times D^2}{6} \text{ or } R = \frac{3 \times W \times S}{2 \times B \times D_2}$$

where W is the load in lbs., S the span in inches, R the modulus of rupture in lbs. per square inch; B the breadth in inches, D the depth in inches.

On Strain and Fracture.

A diagram was exhibited showing the strain and fracture in bars of various materials, as ascertained by experiment, which we give in a tabular form:

	Dimensions of Bars.					
	Span.	Breadth.	Depth.	Breaking Weight.	Deflection	Modulus of rupture.
	in.	in.	in.	lb.	in.	lb. per square in.
Glass fractures	9.312	0.20	0.34	12	—	7250
Glass fractures	9.312	0.20	0.32	12	0.075	8192
Glass fractures	9.312	0.20	0.37	13	0.075	6637
Glass fractures	9.312	0.20	0.32	11.5	0.080	7843
Glass fractures	9.000	0.20	0.32	10.7	—	7053
Sealing-wax fractures	7.000	0.35	0.375	6.5	0.32	1392
Sealing-wax fractures	7.000	0.36	0.36	5.75	0.56	1249
Cast iron fractures	36.0	1.00	2.00			
Cast iron fractures	36.0	1.00	2.00			
				Mean of 81 bars.	Mean of 81 bars.	Mean of 81 bars.
Cast iron fractures	36.0	1.00	2.00	3.571	0.392	48,000

The breaking weights were obtained by means of a graduated lever and sliding weight, and the deflections by an extension of one of the lever ends, which traced a line upon a piece of smoked pasteboard. As the knowledge of the

position of the neutral layer in a beam is of considerable importance to the engineer and shipbuilder, seeing that the moment of inertia, and the consequent moment of resistance, are calculated by rules depending upon the position of the neutral axis of the section whose strength is to be determined, it is hoped that the foregoing may prove interesting to the members of this Institution.

In the discussion which followed the reading of the above paper, Mr. E. Kemp asked whether in his experiments Mr. Millar had tried any other substances but the three mentioned?

Professor Thomson said it was to Mr. Millar that they were indebted for the discovery, that there was a special connection between the place where the load was applied, and the side to which the horn turned in breaking—that when a bar was supported at two ends, and loaded in the middle, the crack seemed to open at the bottom, and the horn pointed to the place where the load was. The fact of horned fractures occurring in connection with the breaking of sealing wax was well known long ago. He had tried it with regard to the basaltic rocks; but, so far as he knew, the connection between the place where the load was applied, and the direction to which this horn turned over had never been specially noticed until now. This was a fact well worthy of being noticed, and a reason sought for it.

Mr. Rowan said it would appear that strains were very capricious in the breaking of these crystalline substances; though none of them broke at the same place, there was a strong family resemblance in the fracture—a fact which perhaps they would never be able to explain. He remembered having to use malleable iron bars, and he could not find reliable data to go by; Mr. Millar could give nothing suitable, and accordingly some experiments had to be made. He asked whether Mr. Millar had taken any notice of them in his paper?

Mr. Millar said he had made some reference to those experiments in his previous paper.

Mr. Rowan said one curious thing was noticeable—the diminishing deflection that took place.

In one malleable iron bar $\frac{11}{16}$ thick, two inches broad, two inches deep, and three feet between the supports they increased the weight to thirty-seven cwt. By occasionally taking off the load it diminished the deflection, which altered each time, until ultimately they had a permanent set. It was quite appreciable, but that was about the limit of that forged malleable iron bar.

Mr. W. R. M. Thomson asked whether Mr. Millar had artificially assisted the breaking of the bars by a slight cut or scratch, at the different distances from the center.

Professor Thomson said one point touched upon in the paper had been discussed in other places, and in books of recent years, namely, as to the position of the neutral lamina. A good deal of confusion had arisen in regard to that as to the difference between breaking a rod under compression, by elastic yielding to compressing force, and not yielding to force. The fact that cast iron will break with much less stress per square inch by tension than by compression, had nothing to do with their yielding more in elastic limits under tension and compression. They had a right to be very certain that the yielding to tension and compression within the elastic limits were just alike.

Mr. R. Mansel said it was very clearly shown by the experiments with polarized light that the section of the neutral plane in glass was near to the center of gravity of the particular section.

Mr. Millar replied that when conducting these experiments the bars could be noticed at times, when near the breaking load, to take a sudden depression and then to break. Mr. Kemp had asked if he had used any other substance in his experiments? He had not done so. The chairman had spoken of the position of the neutral lamina, as it was important for engineers to know its position when calculating the moment of resistance of a section. In the glass bar referred to under the action of polarized light, exhibited at the lecture by Mr. Spottiswoode, so far as he could observe there was no movement of the position of the neutral layer, even though the bar happened to break; it remained midway until the bar snapped, so that apparently the neutral layer lay midway between the sides until the fracture took place. His object in connecting these experiments upon glass bars with cast iron was,

that from the difficulties of dealing with cast-iron bars the deflections and consequent change of figure being so small, much information might be got from the glass bars of what occurred in the cast-iron bars; and seeing that the ratio of compressive strength to tensile strength in glass is about double of what it is in cast iron, and that both substances showed fractures following the same general law, the inference was very strong that the neutral layer of cast-iron bars would lie midway between the compressed and extended sides. Mr. Thomson had asked whether he had attempted to fix the position of fracture by weakening the bar at a particular part. He had not done so with these bars, but he had often done it with cast-iron bars, and the form of fracture had always followed the law of the curve pointing to the center. In some cases he had file draughts made on the cast-iron bars to about the 16th of an inch deep, but the bars had not always broken there. In his former paper he had given what he believed to be the reason for this particular kind of fracture and had demonstrated the same by diagrams of lines of stress. His theory, shortly stated, was that fracture commenced at the extended side, and that as the lower layers were in tension the direction of fracture would be at right angles to the direction of this stress, which would give a fracture running up to the compressed side. If the fracture took place at center of span there would be equal actions on each side; hence a straight fracture would ensue; but if fracture commenced away from the center, the line of fracture would at first follow the same direction as before; but since the longer part of the bar, by reason of its greater curve, would have more spring in it than the shorter part, an unequal action would arise, which would tend to form a fracture running horizontally; the resultant action would therefore give a fracture of the curved forms exhibited.

RIVER IMPROVEMENTS IN FRANCE, INCLUDING A DESCRIPTION OF CHANOINE'S SYSTEM OF FALLING GATES.

By Prof. WILLIAM WATSON, Ph. D., late U. S. Commissioner.

II.

Nearly all the new barrages on the rivers Seine and Yonne have passes closed by Chanoine's system of falling gates (*Hausses mobiles du systéme Chanoine*).

Chanoine's barrage consists of two essential parts, viz., a navigable passage, and an over-fall or waste weir.

The navigable pass serves, when there is a sufficient draught of water, for navigation; the gates being at that time lowered upon a solid bed of masonry prepared for their reception at the bottom of the river.

The weir serves to maintain the river at a constant height, when the gates are raised, by providing for the discharge of the surplus water.

To these essential parts there is usually added a lock, through which the boats pass when the gates are up.

The pass is closed by a series of falling gates, the invention of M. Chanoine, which may be thus described.

Chanoine's falling gate, Fig. 6, consists of a rectangular wooden pannel framed and strongly clamped with iron, revolving on a horizontal axle placed perpendicular to the current.

This pannel is divided by the axle into two parts, the upper, called the chase, and the lower, the breech; to the bottom of the latter a strong wrought iron handle is securely bolted.

The chevalet, or horse (Fig. 3), which supports the pannel, has the form of a trapezoid; the two uprights being connected by one or more horizontal transoms.

The axle of the pannel which forms the cap E of the horse is finished with turned journals, which are held by two cast iron collars secured to the pannel by screw-bolts, nuts and washers. The

lower bar F has also journals which turn in bearings firmly attached to the sill. The height of the horse is about $\frac{5}{12}$ of the height of the pannel, hence when the horse is folded down the pannel folds over it and both lie flat on the platform (Figs. 1 and 2.)

When the barrage is closed the horse is erect, and the pannel abutting against a sill 0.10 m. above the platform makes an angle of about 82° with the horizon; it is sustained in that position against the pressure of the water by a strong wrought iron abutment prop *a e* hinged

Fig. 1. Elevation and section.

Fig. 3. Horse. Section E F. Elevation.

Fig. 6. Pannel.

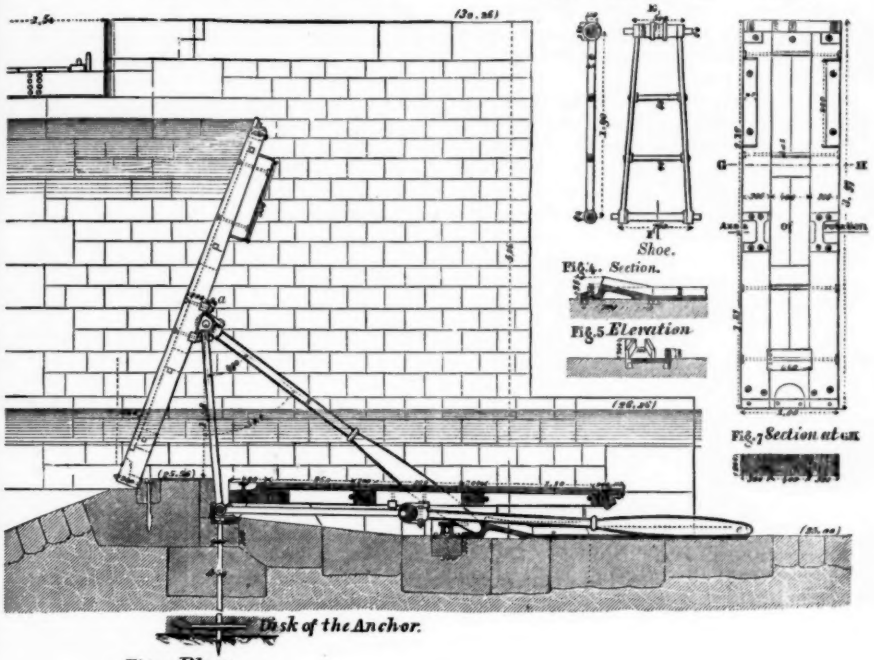
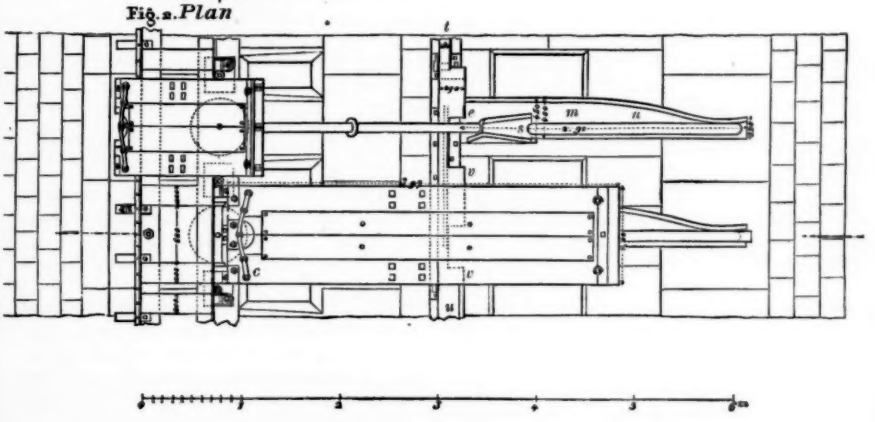


Fig. 2. Plan



to the cap of the horse at *a;* its foot *e* is held by a cast iron shoe or heurter *s* firmly fixed in the masonry platform. This shoe is open at one side to allow *e* to be drawn out into a guide plate *m n* when the gates are lowered. The joint *a* between the prop and the horse, is thus formed; two cheeks are welded to the cap of the horse and between them, the head of the prop is placed and held in position by the pin *a;* to allow the lateral motion of the foot of the prop, the hole at the head of the prop is made larger than the pin *a* which connects it with the horse.

Talon-Bar.—The displacement of the foot *e* of the abutment prop from its support *s* is effected by means of a long horizontal bar *t u*, called a talon-bar, furnished with projections or talons *v v* (Fig. 2) placed at suitable intervals.

This bar is terminated at one end by a rack which gears with a pinion attached to a capstan fixed into the abutment or pier at the end of the barrage; this bar runs on rollers and is so arranged that it can be brought back to its initial position when the gates are lowered.

Method of Lowering the Gates.—If, on account of a freshet in the river, the barrage is to be lowered, the ends of the abutment props are drawn out of their shoes by the talon bars put in motion by men heaving on the capstans; as soon as a prop loses its point of support it slides along the guide plate *m n*, the horse turns the pannel, follows and covers it (Figs. 1 and 2), and the water flows freely over both.

There should always be several decimeters of water on the platform, when this maneuver takes place, to deaden the fall, otherwise the gate would be liable to fracture.

Method of Raising the Gates.—The gates are raised by means of a windlass built into a boat 8 m. long and 2.20 m. wide, made of oak and specially constructed for the purpose; the boat is fitted with a large sheave or pulley at its stem head, and supplied with ropes, fenders, keys, and grappling hooks.

[NOTE. *Fenders.*—The fenders consist of two iron frames hinged to the side of the boat, one forward and the other aft, and terminated by wooden buffers long enough to support the boat against the lifted pannels. Upon these fenders a service bridge is erected, high enough to enable the lockman to examine the down stream side of the gate and assure himself of the position of the abutment prop.

The Keys.—Each key is an iron bar in the form of a T, and is placed within reach of the man at the windlass. The handle of the T is held in a socket let into the gunwale of the boat, and the other end is inserted between the gates.

The Grappling Hook is an iron hook with a long wooden handle; to this hook one end of a long chain is made fast; the other end is carried around the pulley at the stem head and secured to the barrel of the windlass.]

In order to raise the gate next the bank, the boat is placed parallel to the abutment, with its bow projecting half the width of the gate, and secured in this position by ropes; it is also kept at a proper distance from the gate by fenders. When all is ready the lockman puts the grappling hook into the handle of the gate, and his assistant at the windlass slowly winds in the chain; the pannel rises, the horse turns through a quadrant, the abutment prop follows and falls into its place in the cast iron shoe. The pannel in this position is nearly horizontal, the counterpoise, or a slight pressure, brings the breech down and the pressure of the water forces it into its place against the sill; its motion, however, is here moderated by slowly unwinding the chain. The abutment prop is examined to see if it is exactly in its place, and the grappling hook detached from the pannel.

As soon as one gate is raised the boat is pushed forward the width of a gate, and the operation repeated until the pass is entirely closed.

The interval between successive gates is about 0.10 m., hence by inserting the keys, using the fenders, and also with the aid of ropes fastened to a pier or abutment, the boat is held securely throughout the whole operation. Only one gate can be raised at a time: it takes from four to five minutes to raise each gate.

Each of the twenty-two new barrages has a pass closed by Chanoine's system of falling gates, worked by means of a talon-bar and a boat. Thirteen of these barrages have an overfall held by falling

gates, the pannels being worked from a bridge resting on a system of *fermettes*. In six, the overfall is surmounted by *fermettes* and needles with a foot-bridge 0.25 meter above the upper bay; one has Girard's system, which will be hereafter explained in detail. The sills of these passes are generally placed 0·50 or 0.60 meter below the level of the lowest water.

Fixed Portions of the Barrages.—The width of the foundation of the upper bay of the pass of the new barrages with falling gates is from seven to ten meters up the stream; its thickness is at least equal to the fall and rarely less than two meters. Between Auxerre and Joigny it rests directly upon the rock or chalk. Between Joigny and Montereau the mass is formed of a layer of béton poured into a coffer-dam, and upon this mass after the dam had been pumped out the foundation and bed of the upper bay were built, which is partly of cut stone and the rest of rough stone dressed at the joints. In the bed of the upper bay are fixed anchors, consisting of wrought-iron bars and cast-iron plates serving to solidly unite the masonry and the wooden sill against which the bottoms of the pannels strike. The bed of the overfall of these new barrages is usually four meters wide, and has a minimum thickness of two meters. It is either entirely of masonry or else a wooden coffer filled with béton and covered with a masonry pavement.

The overfall or wier lies between a masonry pier 3 m. thick, and 6 m. long, which separates it from the pass, and a masonry abutment connected with the bank by two wing walls.

Below most of the barrages there is a rear bed, or apron, composed of rip-rap kept in place by piles driven in quincunx.

Movable Portions of the Barrages.—The navigable passes of the twenty-two new barrages upon the Yonne are closed by wooden gates 1.25 meters wide and 0.05 meter apart. During the season of low water the interstices are stanched by *couvre-joints*, *i.e.*, pieces of timber 0.25 meter to 0.30 meter wide, and 0.03 meter thick placed above against the pannels. The overfalls of fifteen of these barrages when constructed, were furnished with the automatic gates of Chanoine; these were 1.35 meters wide.

Chanoine's System of Automatic Falling Gates.—When a pannel is erect, as long as the resultant of the pressure of the water passes below its axis of rotation it remains erect; if, however, this resultant should pass above the axis of rotation the pannel would overturn. We may thus divide the gates into two classes according to the relative positions of their axis of rotation; these classes are designated by M. Chanoine as automatic and non-automatic gates.

It is evident, that as the center of pressure of the water on a rectangle is situated at one-third its height, if the axis of the pannel is so placed that the length of the chase is twice that of the breech, the pannel will turn spontaneously when the water rises to the top. It may be brought back when the water has fallen by the action of a suitable counterpoise.

The pannels of the pass have their axes of rotation higher up than those of the overfall and do not fall spontaneously, but by the aid of talon-bars moved by capstans; they are raised by a boat.

The pannels of the weir, on the contrary, were made to fall and rise themselves, on account of the position of the axes of rotation, which is 0.05 meter, above one-third the height of the pannel, and by the action of a suitable counterpoise. The ingenious system of automatic gates for the overfall was at first highly esteemed on account of its simplicity and its success on a single barrage, as a means of disposing rapidly of the surplus water of a freshet without emptying the upper bay or interfering with the navigation of the stream; but great difficulties arose when it was tried in 1868, on a large scale, for the continuous navigation of the Seine and Yonne between Paris and Laroche. The floods of the *éclusées* from the Yonne, which were ponded above Laroche, or a little freshet, produced disturbances in the upper bays and overturned all the automatic gates; that is to say, an elevation of water from 0.09 to 0.14 meter above the crown of the pannels was sufficient to overturn them. They did not shut again until the water had fallen 1 meter in the upper bay, thus stopping

navigation and exposing the barges to grounding.

Notwithstanding the zeal and devotion of the lock-men and employés of every grade, it was impossible to prevent this disorder as long as the gates were not worked directly by the lock-men themselves; hence the engineers did not hesitate to propose the establishment of service-bridges above the overfalls with gates; this proposition was approved in 1868 and carried into effect in 1869 and 1870.

The SERVICE-BRIDGE is composed of iron *fermettes*, like those of the needle barrages, of Poirée, movable round a horizontal axle perpendicular to that of the overfall. Each *fermette* corresponds to the axis of a pannel. These *fermettes* are united at their tops by two connecting-bars, which limit the width of the walk; between these bars a flooring is placed 0.50 meter above the level of the water. The two connecting-bars are rails upon which the crab-engine rolls. Finally, to this crab-engine are attached two chains, one to the upper and one to the lower edge of each pannel. By the aid of the crab made fast to one or two *fermettes*, and with the two chains, every necessary maneuvre is made without fatigue and without danger. In times of freshet, the connections between the *fermettes* are taken off in succession, commencing at one end. The first frame, relieved of all connections, revolves on the axis at its base and falls into a chamber in the platform on the bed of the river. The second frame is then disengaged and lowered over the first, and so on to the end; the height of the frames being greater than the interspaces, they lie partly over each other in the chamber prepared for their reception in the platform on the bed of the river, and in which they are below the level of the sill, and so protected from injury. The frames next the wing-walls fall into a recess in the masonry. The bars and the crab are stored. It is alleged that the gates of the overfalls should not have counterpoises. These service-bridges have been also established at the two old overfalls of Pechoir and Saint Martin, which have a special kind of gate movable around an axis fixed to the up-stream crown of the overfall.

The new system has been a perfect success. Every night the lock-man is warned of the variation of the water in the upper bay by an alarm put in motion by a floater. In addition, all the barrages are united by telegraph, and the system, thus complete, prevents all surprise.

The experiment made in 1868 upon the working of the twenty-nine barrages constructed upon the Seine and Yonne has served as a basis for the new plans for improving the Yonne between Laroche and Auxerre. New barrages were planned with a movable pass closed by falling gates, and an overfall with needles and *fermettes*. Six of the barrages between Laroche and Auxerre have this system of overfall.

LOCKS.

Dimensions, form, and mode of construction.—The three old locks have their walls vertical of solid masonry; the head-walls are 2.50 meters thick. Fifteen of the new locks have the heads and masonry gate-chambers with vertical walls, the rest of each lock-chamber is included between two walls, whose outer faces, sloping at an angle of 45°, are protected by stone pitching. They rest upon a mass of sheeting or masonry, reposing either upon a solid bottom or secured by rows of piles and sheeting.

For the river-locks, the dike which forms the side-wall is three meters thick at the top, with an exterior side-slope of $\frac{2}{3}$, protected by stone pitching. The coping is masonry. The dike, constructed of earth, with a central core of rammed clay two meters thick, is generally very tight.

M. MILNE-EDWARDS has been elected President of the Scientific Association of France, created by M. Leverrier. The Association has organized a series of lectures at the Sorbonne, to describe new inventions and discoveries. M. Cailletet's experiments on the liquefaction of oxygen, air and hydrogen will be exhibited at the first meeting, which will soon take place. They will be explained by M. Henri St. Claire Deville. It is stated that M. Dumas intends to propose a subscription for erecting a monument to Leverrier.

PROFESSOR SKINNER UPON MOMENTUM AND VIS VIVA.

By S. BARNETT, Jr., Edinburgh, Scotland.

Written for VAN NOSTRAND'S MAGAZINE.

WE do not propose to review the whole of this article (VAN NOSTRAND'S MAGAZINE, Nov. & Dec., 1877), but only such parts as relate to Prof. Tait's lecture upon Force before the British Association at Glasgow, printed in *Nature*, (Sept. 21, 1876). The mistakes into which Prof. Skinner has fallen arise principally from two causes; a misunderstanding of the question to be solved in establishing an absolute unit of force, (for, he says, he can see no reason why the absolute unit should be called so), and an excess of zeal for controversy. After mentioning various views of force by different writers, he says, "and we have lately had the eminent Prof. Tait define it as the *rate of doing work*." Prof. Skinner asks, as if conclusive of the matter, whether the weight of a penny letter, the unit of force, "can be regarded only as a *rate of doing work*." It may appear to the unscientific at first sight a little artificial so to define force. But this is so only because the unscientific are unaccustomed to define force at all. The day laborer who works from morning till night would consider it extremely absurd if you were to tell him that work was the product of the resolved part of the force along the line of displacement into the displacement. There is a vast difference between knowing generally that a force is "any pull, push, pressure, tension, attraction or repulsion," and being able to establish a unit of force which can be found at any time or place, even though, however improbable such an occurrence may be, all spring balances and platinum units of mass should be simultaneously destroyed, and the earth itself should suddenly contract or expand in volume. Prof. Skinner either does not see that this is necessary to a unit of force being absolute, or he completely ignores it.

Instead of rate of change of momentum or rate of doing work, Prof. Skinner calls force a *pressure* or *tension* measurable in *pounds*. He goes into quite an elaborate argument, quoting from Newton, and giving the results of experiments with Attwood's machine, to show that *force* is simply *pressure* or *tension*. Yet how are we benefited by this knowledge? We know force as well as tension, and it would have been equally instructive to prove that *tension* was *force*. By this, however, he means to prove that inasmuch as force is tension it is not the rate of doing work. Prof. Skinner seems to forget that it is necessary for him to know what tension is before he can say what it is not. It should be remembered that the pound is not a weight but a mass, viz., the platinum block kept at London, in the Exchequer Chambers. The pound weight, however, is a force, yet a variable one. The pound weight is different at different parts of the earth, and different at the same place at different times unless the dimensions of the earth are rigorously invariable. A unit of weight then is a delusion; there is, and can be, no such thing. Yet Prof. Skinner assuming the usual units of time, length and mass, proposes as follows to *derive* the unit of force from them; for, choosing any three of these four at pleasure, he says "nature imposes a connection between the fourth and the others," and, therefore, this fourth can be derived. And this he does by assuming the unit of force to be equal to the weight of the unit of mass in the place where it is kept. But this weight will vary with possible variations of gravity at London. To render the unit of force independent of this, Prof. Skinner proposes at a particular time to provide a spring balance and note the distortion due to the weight, and to define the unit of force, the force due to this distortion. The reader may have noticed that this makes the unit of force depend solely upon the perfection of a dynamometer, independently entirely of the units of time, length and mass; Prof. Skinner has thus by two steps severed the connection which nature had imposed. But the most significant fact is the method by which Professor Skinner proposes to establish a check, or to verify his spring dynamometer

He says, "the results of this weight, at the given time, in maintaining the distortion of a spring, and in producing motion could, of course, be recorded."

Evidently, the recording the amount of motion the spring is capable of producing, saves the necessity of postulating its perfection. But then this record dispenses with the necessity of preserving the spring; the record is necessary and all sufficient. The subterfuge of the spring serves only to blind Prof. Skinner to the completeness of his surrender to Prof. Tait's principle of measuring force by the rate of change of momentum; and not only Prof. Tait's but Newton's, and the method of the scientific world since his day.

It is hopeless to expect to establish any invariable units dependent upon aggregations of matter. The whole universe, the stars, the planets, our standards of masses, and lengths, and all spring balances are evanescent and must change some time or other. The "absolute" measure of force, to which Prof. Skinner raises objections, and of all our other units is independent of any such aggregation. The units of time and length may be made to depend upon the time of vibration and length of wave of a particular kind of light, and thus absolutely determined for all time. All the other units may be made to depend upon them. For example, the unit of mass may be defined by its relation to that mass which, by its attraction of gravitation, at unit distance, will produce unit velocity in unit time; the unit of force, as that force which by acting for unit time on unit mass will produce unit velocity; unit of velocity of course being that of a body moving over unit length in unit time. Thus the units of density, momentum, work, Potential, Electricity, etc., may all be made to depend immediately upon those of time and length.

The second law of Newton, from which the above definition of force is deduced, reads as follows: *Change of motion is proportional to the impressed force and takes place in the direction of the straight line in which the force acts.*

W. O. P. (*Nature*, Oct. 26, 1876), quoted with approbation by Prof. Skinner asks, "has not Prof. Tait confused the idea of *measuring* something with the idea of *being* something." Prof. Tait has simply distinguished the phenomenon, which is all that an exact science has to deal with, from those metaphysical speculations which are beyond the reach of experiment. It is not pretended that the rate of change of momentum is both the first cause and the final effect; it is only the phenomenon and, therefore, all that science is to recognize. The substitution of rate of change of momentum for force in the above law renders it tautological, because it is of the nature of a real definition, embodying all that we know of force. What may correspond in the outward world to our sensations of muscular tension is simply speculation. We see only motion; even when ourselves exerting muscular tension the motion produced, not the sensation, is a measure of the force; the compression of a spring means nothing to us except what momentum it has been previously found to create or destroy. Newton here recognizes no balanced forces. Impressed force produces its change of motion. In fact when we consider that there are no fixed boundaries in space, but that motion is motion only with reference to some arbitrarily chosen fixed origin, this becomes self-evident. Every force according to Newton does work. For, if with reference to any fixed origin, arbitrarily chosen, the body be at rest, remove one force the others remaining as before; thus may be seen the work the force destroys. But the destruction of work is simply doing work in the opposite direction. The penny letter resting upon the table has work done upon it by gravity; the resistance of the table does an equal amount of work in the opposite direction. This is excessively simple and undeniable when understood.

Prof. Skinner should be careful not to claim more for Thomson and Tait than they claim for themselves. In comparing the accuracy and simplicity of the absolute units given above, with the clumsy ones adopted in many text books (Nat. Phil. p. 166), they observe "that the assumption of the unit of mass as g times the mass of the platinum pound gives a variable unit, g itself at London not being constant." Yet Prof. Skinner quite irrelevantly asserts that 32,1912 times the standard pound is invariable. This is quite true and may be admitted

without prejudice to any thing said by Thomson and Tait. Let us now test Prof. Skinner's unit of force in the light of his own formulæ. The formula $M=\frac{G}{g}$ he says "will give the mass, provided G be the weight measured on a standard spring balance, and g be the acceleration of gravity at the place."

Here we have the means of obtaining the dimensions of weight and thus of discovering what Prof. Skinner's force really is. The formula gives the weight $G=Mg$, of which the dimensions are mass times acceleration. A weight then is simply a rate of change of momentum. Prof. Skinner then has simply stopped too short; he can verify his dynamometers only by change of momentum, and when the dimensions of weight, and therefore of force are found, force itself is found to be nothing but rate of change of momentum. This definition is implied in every equation in dynamics.

We pass on towards the last of Prof. Skinner's article. He says that he cannot agree with the view that force is a mere rate of change of momentum, and that it seems to him a sufficiently good reason for rejecting it, that the intensities of forces may be measured without having any thing to do with momentum, simply by measurements upon a spring balance, while not (apparently) doing any measureable work or changing momentum at all. The above amounts simply to saying, that we can devise an instrument, viz., a spring, by which the observer may infer the amount of work done upon a body, even when the observer and body have no relative motion. It is inconceivable that a single force should act upon a body and leave it in the same state as before. If two equal and opposite forces, as gravity and the resistance of a support, come simultaneously into action, the work done in one direction is equal and opposite to that in the other; but each force does or destroys its proper amount of work. We have run the risk of being tedious here, and of repeating, because Prof. Tait's concise treatment seems to have contained many points that have been overlooked.

Prof. Skinner says that we have as good a right to call force rate of change of vis viva per unit of distance as of momentum per unit of time. This can scarcely be an objection, as the two are mathematically identical, and are employed indifferently for force throughout the whole of dynamics and of mathematical physics. Besides, even though Prof. Tait were not in the habit of using either indiscriminately, as he is, it would not be much of a compliment to his mathematical knowledge to suppose he had never observed the identity. Next, Prof. Skinner asks, "can the equation $F=\frac{\frac{1}{2}MV^2}{D}$ be any part of what Prof. Tait alludes to when he says, 'a simple mathematical operation shows us that it is precisely the same thing to say:

"'*The horse-power or amount of work done by an agent in each second is the product of the force into the average velocity of the agent*, and to say :

"'*Force is the rate at which an agent does work per unit of length.*'"

Prof. Skinner adds, "What his simple mathematical operation would be, I do not know ; for I never saw it stated elsewhere that *the horse-power done by an agent in each second is the product of the force into the average velocity of the agent*, or that *the horse power in each second* is such a product, or even that the *horse power* is that product."

When Prof. Skinner says he never saw these things stated elsewhere, it is to be supposed that he thinks he sees them stated here. Prof. Tait uses as synonymous terms *horse-power* and *amount of work done by an agent in each second*. If Prof. Skinner sees in that anything about *doing a horse-power in a second*, or even a *horse-power in a second*, there is an end of the discussion; and the matter has become a mere question of sight.

It would be tedious to examine closely every objection urged by Prof. Skinner. We omit a number, and among them the question of the comparison of force and momentum. Prof. Tait in his lecture calls attention to the fact of there being of different dimensions in the units of time, length and mass, and that for that reason the mathematician would no more think of comparing them, than, as Hopkins used to say, of measuring heights in acres, or arable land in cubic miles. This seems to Professor Skinner an argument of no validity; for, among

other things, he notices that force and momentum are sometimes *numerically* equal. The same is true also of a square and a cube, but for that reason in itself they can neither be denied nor affirmed to be the same thing.

"Again, Prof. Tait says that the mathematician expresses the distinction between force and momentum by saying that 'momentum is the *time integral* of force, because force is the rate of change of momentum,'—both of which propositions" says Prof. Skinner, "appear to me objectionable." We are unable to say why he calls this "both." There is but one proposition; Momentum $=\int dt$, because Force $=\frac{d}{dt}$ (Momentum). We do not ask why he calls it both from a desire to criticise small points, but if possible to throw light upon what Prof. Skinner understands a time integral to be. We find next the following: "I have already given some reasons for rejecting the idea that force is a mere *rate of change*; and how can momentum be properly said to be the *time integral* of force, when *any amount* of momentum can be produced in *any time* by a force of the proper intensity? It appears to me that the *integral* of any quantity ought to be equal to the sum of all its increments from zero. But a *constant* force can have no increment and therefore no proper *integral* dependent on time." We cannot imagine what Prof. Skinner understands by a time integral. The time integral of force is really $\int_b^a F dt$, where F is a function of t. Prof. Skinner certainly will not maintain that this integral can not be finite when the limits of integration are infinitely close together; or that the above is no proper time integral at all when F is constant? It is possible he had some other integral in mind, especially as he says that an integral is the sum of all its increments from zero, and this is true only of the simplest possible of all integrals $\int_a^c dx$. But even granting with him that a constant force has no proper time integral what are we to say of the following? Since then, he says, a constant force has no time integral, let us consider a variable force. He then lets a force equal to one pound act for the first second, a force of three for the next, five for the next, etc. For these he finds a proper time integral. That is, though a constant force has no proper time integral, the sum of a number of these improper or impossible quantities gives as a result a proper time integral. Now any one who adopts a unit of force different from the one given by Prof. Tait necessarily finds himself involved in some inconsistencies; but has not Prof. Skinner needlessly complicated matters?

"Prof. Tait asserts that force is not an objective reality but a convenient abstraction—a mere name—and that the *product of a force into the displacement of its point of application* has an objective existence. How the product of a *mere name* into the *displacement of its point of application* can have an objective existence, while that which the name denotes cannot, I leave to the metaphysician." Prof. Skinner here, for the sake of argument, grants that force is merely a rate of change, and he thinks it necessary immediately to introduce the metaphysician. For our own part we consider the metaphysician entirely superfluous. The death rate into the number of people in a city will give the number likely to die there in a year.

The following quotation shall be our last, "Prof. Tait, at the end of his lecture, says, that 'in defense of accuracy, which is the *sine qua non* of all science we must be zealous as it were even to slaying.' Whether the points of the lecture to which I have called attention are merely slips, due to the unpropitious circumstances of time, place and surroundings, under which he says the lecture was prepared, or whether he would if he thought it worth while show that my objections are groundless, I do not venture to say. But if his position is not sound, the high and well earned fame attached to his name may make the lecture a source of much future confusion, so that I have thought it worth *my while* to consider it here at some length."

We are sorry that Prof. Tait's "zeal" in "slaying" has not yet called forth anything further from him. Possibly he considers his position sound, and trusts that, though on a first reading a few old notions may be uprooted, a careful study of his lecture is not likely to produce confusion, but on the contrary, quite the reverse.

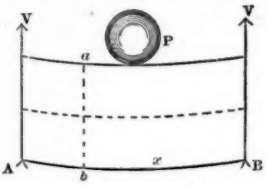
NOTE ON THE MISAPPLICATION OF CORRECT THEORIES.

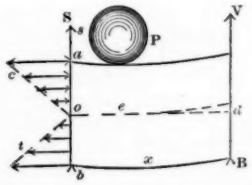
By DE VOLSON WOOD, C. E., M. A.

Written for Van Nostrand's Magazine.

In the last December number of this Magazine, on page 524, Mr. Crehore states that "I suspect that no late authority disputes the equality of the total moments on each of the two sides of the neutral surface."

If the Science of Statics is correct, the equality of moments here assumed is impossible. Take the case of a beam supported at its ends and loaded at the middle. The vertical reactions at each end will be $V=\frac{1}{2}P$. These forces develop internal stresses. Make a vertical section ab at a distance x from the end B. Remove the part Ab, and in the sec-





tion ab introduce forces which produce exactly the same strains on the elements of the beam as existed before the section was made. According to the principles of Statics the algebraic sum of the vertical forces will be zero; hence, according to the notation in the preceding figure, we have

$$S_s+P+V=0$$

Let P be position downwards, then will $V(=\frac{1}{2}P$ in this case) be negative, and we have

$$S_s=V-P=-\tfrac{1}{2}P$$

which being negative shows that it acts upward. The vertical force in the section is called *a vertical shearing stress.*

According to the same principle of Statics, the algebraic sum of the horizontal forces will be zero for equilibrium. The only horizontal forces in this case are the pulls and pushes of the forces in the section. Let t be the sum of tensile forces, and c the sum of the compressive forces in the section ab, then we have

$$t+c=0$$
$$\therefore t=-c;$$

or they must be equal and contrary. These forces are equivalent to a couple.

Lastly, according to Statics the algebraic sum of the moments of all the forces in reference to any point must be zero. Take the origin of moments at o on the neutral surface. The forces producing tension tend to turn the system in the same direction as those producing compression,—in this case right-handed —hence they have the same sign and cannot be equal to each other. Draw od horizontal, and take e directly under P; then will oe be the arm of the force P, and od that of V.

Also let T be the resultant of the tensile forces, and f its arm, and C and g, the corresponding quantities for the compression ones, and we have

$$T.f+C.g+P.oe-V.od=0$$

The values of P and V cannot both be made to disappear at the same time from this equation, hence we cannot even have

$$T.f=-C.g$$

for equilibrium. Therefore, we see that the hypothesis that these moments equal each other must be erroneous. Neither does it help the case by showing that the equation founded on this hypothesis, represents the results of experiments exactly, unless, indeed, we are prepared by such a coincidence of results to overturn the fundamental principles of Statics. The truthfulness of these equations and conclusions should not, therefore, be

called in question any more than we should deny the soundness of the laws involved in Maclaurin's and Taylor's Series, because these laws are not applicable to all functions. But the laws of Statics would indeed be applicable to the case if the law of action of the internal stresses were known. After the strain passes the elastic limit, it is certain that the stresses do not increase directly with the distance from the neutral axis. It is not probable that the neutral axis remains at the center of the cross sections at the time of rupture, and this combined with the fact that the law of the stresses is not only complex, but really unknown, prevents us from establishing the true equation of rupture. The only thing necessary in order to make a correct theory in regard to rupture, is to determine the correct law of action of the internal stresses at the instant of rupture.

Navier, in his earlier lectures *assumed* the equality of moments on opposite sides of the neutral surface, but in the second edition of his work the correct statement was substituted for it,—that the *forces* on the opposite sides were equal. Similarly, Barlow, several years after Navier's correction, assumed the same error in regard to the equality of the moments. In neither case was there any analysis to prove the assumption. The true conditions were stated by Coulomb more than a century ago.

The crushing resistance of wrought iron cannot be definitely determined, for wrought iron does not yield suddenly to such a stress. The values given in the writer's "Resistance of Materials" have a great range, some even exceeding the ordinary tensile strength of that metal. Therefore, the remark "that the crushing resistance of wrought iron is from $\frac{1}{2}$ to $\frac{3}{4}$ as much as its tenacity," has been omitted in the editions of that work subsequent to 1871.

ON SCHOOLS OF FORESTRY.

By Rev. J. CROUMBIE BROWN, LL.D.

Abstract of a Paper presented to the Scottish Arboricultural Society.

The Schools of Forestry on the Continent of Europe are educational institutions, in which provision has been made for leading candidates for employment as foresters through a protracted course of study, similar to what is required in Scotland as a preparation for the so-called learned professions of law, medicine and divinity.

They may be considered as a necessary requirement of the system of forest management introduced on the Continent of Europe in the beginning of the present century, and also as a means of advancing the *Forst-Wissenshaft*, or Forest Science of the day, and of promoting its application to the treatment of forests, so as to secure the greatest benefit from the system of forest economy considered the best adapted to the circumstances and condition and requirements of any particular case.

Some three hundred years ago it was perceived by Sully, the distinguished minister of Henry IV., that France was being ruined by the destruction of her forests; I almost quote his own words. And a hundred years later there was passed in 1666 a famous ordinance to regulate the exploitation of these. The evil was not confined to France, and for a hundred and fifty years, in France and elsewhere, various measures were devised and adopted with a view to averting the catastrophe; but it was found that these could at best only retard the destructive process. At length Hartig and Cotta devised what is known in Germany as the *Fachwerke methode* of forest exploitation, the aim of which is to secure simultaneously, and without prejudice to each other, a sustained production of wood and timber, a progressive amelioration of the state of the forests, and a natural reproduction of these by self-sown seed.

In India, as in France and in Germany, it was found that the forests were being

destroyed, that the destruction of these was entailing privations and sufferings upon the people, and that more disastrous consequences were looming in the distance. After careful deliberation, it was determined that a body of forest officials, educated at schools of forestry on the Continent of Europe, should be procured.

The expense was considerable, and it may be considered that this was a bold measure, but the results have justified the steps taken. By progressive amelioration of their condition, forests there have risen greatly in value and have been vastly extended, and the revenue from forests has been increased by *hundreds of thousands of pounds.* All which has been accomplished—not by an impoverishing of the forests, but by a progressive amelioration of these and an increase of their pecuniary value in something like a corresponding ratio.

In illustration of this latter allegation, I cite the following statement, made by Captain Campbell-Walker in a paper on "State Forestry: its Aim and Object," read before the Otago Institute, Dunedin, 21st December, 1876:

"The Chunga Munga plantation, in the Punjab, has an area of 7000 acres, commenced in 1865, contains chiefly Indian black-wood (*Dalbergia sissoo*). The expenditure up to end of 1873 had been £26,000, including £5,000 spent during the first five years in unsuccessful experiments; £5,000 had been received from petty thinnings (firewood and minor produce, grazing dues, etc.). From a careful valuation, and calculations made in 1873, it is estimated that the expenditure up to 1881, when the capital account closes, will be £97,000, and the value of the plantation be then £170,000. In considering the above results, it must be borne in mind that the rainfall in the district is under 15 inches, with great heat in the summer, and sharp frosts in winter. The whole plantation has to be irrigated from a neighbouring canal, being debited with a charge of 4s. per acre per annum for the use of the water alone. Another important fact must be mentioned, viz., that, whereas the land on which the plantation stands was formerly almost valueless, and would not fetch an annual rental of 2s. per acre; 12s., and even 20s. per acre is now readily obtainable, and the former has been offered for the whole or any portion when cleared. The rents mentioned, of course, include the water-rate of 4s. per acre per annum. This plantation is intended eventually to cover 30,000 acres, and will undoubtedly prove a great success, both as regards direct financial profit, a supply of timber or firewood, which is much required, improving the soil, and rendering it fit for cultivation with cereals, and ameliorating the climate. The Nelambur teak plantations, in Madras Presidency, cover 3,000 acres, the oldest portion having been planted thirty years ago. The total expenditure, including purchase and lease of some 19,000 acres of land from a native raja, has been £30,000, and the receipts from thinnings, etc., £10,000. These plantations were valued last year at minimum rates at £150,000, and Colonel Pearson, lately officiating as Inspector-General of Forests in India, estimated their value, when mature, at no less than two millions sterling."

An examination of the programme of study will show that in most of the schools of forestry on the Continent of Europe the course of study is similar, most of the modifications being attributable to national or local conditions. It embraces, besides, matters pertaining specially to forest economy, studies which may be called preliminary or fundamental, and studies which may be called accessory or supplemental.

In the programme of study followed at Aschaffenburg, in Bavaria, which extends over two years and a half, we find that during the first summer session attention is given to Botany, Zoology, the Chemistry of Vegetation, Natural Philosophy, Mathematics, Chart Drawing, and Political Economy.

In the winter session following, instruction is given in Forest Economy, the Game Laws, Botany, Zoology, Chemistry, Mineralogy, Atomics, Hydrostatics, Pneumatics, Heat, Acoustics, Optics, Magnetism, Electricity, Meteorology, Trigonometry, Mensuration of Solids, and Plan Drawing.

In the second summer session there is continued the study of Forest Mensuration, Meteorology, Botany, Zoology,

Chemistry, Land Mensuration, and Plan Drawing.

In the second winter course attention is given to the Systematic Management of Forests, according to different objects aimed at; and the Historical Development of Forest Economy, Forest Technology and Finance, the Timber Trade, the Management of State Forests, Entomology, Organic Chemistry, Geology, Road-making, Dam-making, and Bridge-building, and practice in Forest Mensuration in its every department.

In the concluding summer session attention is given to the practical application of all previous instruction, and instruction on excursions in the whole round of forest operations, instruction in Forest Administration, in Rural Economy and Agriculture, and in all works of Forest Engineering.

Facilities for the prosecution of field and forest studies abound in the vicinity of Aschaffenburg, but the excursions take in a wider range, and extend to the Black Forest, to the forests on the Rhine, and to the pine and fir forests of France. All of these are conducted by the professors or teachers.

There may be much in such a curriculum of study as this which is not deemed requisite as training for the management of British woods and Colonial forests. On this point I have no design to raise a controversy at this stage. The position which I take up is this: The Governments of almost every country on the Continent of Europe—Denmark, Holland, Belgium, and perhaps Greece, being apparently the only exceptions—under the influence of students of forestry, have deemed it expedient to make provision for the instruction of officers in their forest service in all of the subjects embraced in that curriculum. The British Government of India have deemed it expedient to do the same, in so far as existing arrangements permit of this being done, and have found their advantage in the result; and in view of this I raise the question, May not something similar, but adapted to meet the requirements of our conditions, be done by us?

In the location of the schools of forestry on the Continent, considerable diversity exists, and the knowledge of this may be of some importance in considering what may be done.

In some countries the schools of forestry are distinct separate institutions; in others they are connected with other educational arrangements, which in some, but not in all, are in part utilized, and, so to speak, made subservient to the education and instruction of the students of forest science.

Of these, the schools of forestry at Stockholm in Sweden, at Evois in Finland, at Lissino in Russia, at Nancy in France, at Vallombrosa in Italy, and in the Escurial in Spain, are exclusively schools of forestry. The school of forestry at St. Petersburg in Russia is located on the same grounds with a school of agriculture, but in separate buildings. Of the schools in Germany cited, those at Neustadt, Eberswalde in Prussia, and at Munden in Hanover, are exclusively such. The same may be said of that at Aschaffenburg in Bavaria, but it has just been raised to association with the University of Munich. And that at Giessen in Hesse-Darmstadt is incorporated or embodied as one of the faculties in the University of that city. At Tharand in Saxony, and Hohenheim in Wurtemberg, the schools of forestry are connected with schools of agriculture and rural economy; at Carlsruhe, in the grand duchy of Baden, the school of forestry is combined with a college of engineers in the Polytechnicum of that city.

One advantage of such combinations is, that many subjects may be studied by students of different faculties under the same teacher, as is done in the arts classes of our Scottish universities by students contemplating the study of theology, of medicine, or of law; and one staff of instructors thus suffices for the whole, with only special instructors for special subjects of study pertaining to the different professional departments, who conduct their students through these in the same sessions in which they prosecute the studies required of all. There are many advantages found to be connected with the location of a school of forestry in the vicinity of a forest, in which from time to time illustrations of what is advanced in the class-room may be found. But this is not indispensable to the successful teaching of forestry.

It may be said that one-half of the schools of forestry are not so situated, and, even in those which are, the students are taken to see actual forest operations at a distance. The students at the Laesnoi Corps, St. Petersburg, are taken to Lissino, seventy versts, or nearly fifty miles distant. Those at Nancy, in France, are taken to study forest work in the oak forests of Central France, in the coniferous forests of the Vosges and the Jura, and in the perimeters of *reboissement* and *gazonnement* on the Alps. And the students at Aschaffenburg, in Bavaria, are taken, as has been stated, to the Black Forest, to the forests on the Rhine, and to the pine and fir forests of France. I cite only cases on which I have reported, but there are others in which advantage is taken of the facilities afforded by railways for taking students to study practical forestry in districts at a great distance from the locality in which the school of forestry is situated.

It seems to me that the facility for locomotion supplied by railways, combined with the fact that the local expense of board, etc., is very much the same everywhere, has somewhat modified the views once entertained in regard to the location of a school of forestry, in, I shall not say "a cottage," but a palace, "near a wood,"—for in such some of the schools of forestry on the Continent have been located. I may be allowed to state in this connection that, on the publication of my plea for the creation of a school of forestry in connection with the proposed Arboretum, one of my correspondents, Professor Blomqvist, director of the school of forestry at Evois, in Finland, wrote to me on this point, calling my attention to views expressed at a convention of State foresters, etc., at Freiburg, where it was said to be unanimously agreed that a university was the proper place for the study of forest science.

REPORTS OF ENGINEERING SOCIETIES.

ENGINEERS' CLUB OF PHILADELPHIA.— At a meeting of the club held March 16th Mr. Rudolph Hering read a paper on "Bearing Piles," giving formulae for their sustaining power, size and disposition in any foundation. There has been much uncertainty in the minds of many practical engineers regarding the proper formula for pile driving.

Piles were divided into two classes. The first class consisting of those which are driven to a solid foundation and act as pillars or columns of support, and which are therefore designated as *columns*. The other class consists of such as derive their supporting power from the friction of the material through which they pass. These alone are properly called *piles*.

Experience has proven that quick blows with a heavy ram give greater penetration at a less expenditure of power than slow blows with a light ram. In sand or silt the blows should follow rapidly, in order to prevent the ground from settling around the pile before the next blow of the ram.

On account of the many uncertainties in connection with piles a wide margin of safety in loading them is recommended by all authorities. It is sometimes impossible to tell how much of the sustaining power is due to a solid bottom and how much to friction alone. There is often no guarantee that a pile will not steadily sink under a heavy quiescent pressure applied continuously, when it withstood perfectly a corresponding sudden blow from the ram. This is especially to be feared in clayey soils.

The vibrations of the structure may in time produce unexpected settlements; this may also occur when certain clayed soils become very wet adjoining the piles, and the friction is thereby lessened.

A table of safe loads, giving a comparison of values taken from the works of all the authorities on the subject, was exceedingly interesting, and from it the following was deduced: That all formulae, developed from purely theoretical speculation, regarding the resistance of the frictional surface of the pile in the ground, vary greatly among each other and are also unreliable for other reasons.

The only method which can be depended upon in calculating the sustaining power of piles held by friction is the experimental one, which introduces the actual distance which a pile sinks under the last blow. The formulae developed from experiment also differ very much as usually given, but when properly analyzed, classified and compared they will enable the engineer to make an intelligent selection and to obtain a perfectly satisfactory result.

Mr. William A. Ingham called the attention of the Club to some drawings, which had just been received from Europe, of "Steam Boilers and Engines for high pressures," by Mr Loftus Perkins of London. These engines are compound, having three cylinders of proportionate sizes.

In marine engines of this pattern it is customary to use nothing but fresh water in the boiler, and to use this over and over again. This is easily accomplished by thorough condensation of steam used and by avoidance of all leaks.

Mr. H. C. Lewis made some very interesting remarks on the erection of the temporary bridge at New Brunswick, over the Raritan river.

Mr. Charles E. Billin exhibited a new form

of tripod for transit and level instruments, which is being manufactured by Messrs. Heller & Brightly, of Philadelphia. The instrument is a combination of the ball and socket motion and the four leveling screws. By its use fully two-thirds of the time necessary in field operations is saved, as the instrument can be set up and approximately leveled in an instant without the use of the leveling screws. The various parts of the instrument were described, and it was stated that any make of instruments can be altered to this greatly improved form at a very small cost.

At a meeting of the Club, held April 6th, Mr. D. McN. Stauffer made some remarks concerning recent developments relative to the South Street Bridge. Borings had been made about 20 feet distant from each end of the pier which caused the fall of the structure. At the south end, which did *not* sink, gneissic rock was found 37 feet below the surface of the marsh. The rock was overlaid by 18 to 20 inches of gravel, and then a considerable thickness of a hard, very compact yellowish clay.

At the North end, which failed by sinking, the same gneissic rock is 33′ 8″ below the surface. On top of the rock is 3′ 8″ of black mud and above this about 7′ of gravel. This tongue of mud running under the North end of the pier was doubtless the cause of the trouble.

The piles were driven nearly through the gravel stratum, friction of the material resisting further driving. Lubrication of the piles by the slow percolation of water, aided by the vibration of the structure produced by travel on the bridge, destroyed this frictional value, and threw additional weight on the toe of the piles. Supposing this to have been the case, with a yielding material under the gravel stratum, sinking was inevitable.

Prof. L. M. Haupt read a paper "On the proposed removal of Smith's Island." This is a question affecting directly a large number of the industries of this city. The commercial interests of Philadelphia have developed to such an extent as to create a demand for greater wharfage facilities with deeper water; and that cereals and merchandise may be delivered without too many handlings, it is desirable that cars should be run immediately alongside the vessels to be laden. To accomplish this it is proposed to lay tracks on Delaware Avenue, already too narrow, and to make provision for the space thus occupied by extending the Port Warden's line further out, which will contract the channel, now only about 800 feet wide in its narrowest part. Some of our largest shippers have requested permission to extend their wharves several hundred feet. Were this done in a few isolated cases, it would introduce dangerous barriers to navigation, and if an advance were made all along the line it would seriously contract the channel, unless a portion of Smith's Island were removed.

To widen the channel to 1,000 feet, along the Smith's Island front and to a depth of 18 feet, would require the removal of 5,000,000 cubic yards of material at a cost of about $1,000,000.

The same depth and width of channel may be obtained, if desired, for less than one-tenth the cost of dredging, by a careful adjustment of the *regimen* of the river by auxiliary constructions, such as jetties, rip-raps, sand-fences, or bottom-dams.

A comparison of all the maps and records, shows an average movement of the lower end of the Island up stream from Christian Street to South Street, a distance of 1,900 feet in 106 years, or from 1762 to 1868.

SOCIETY OF ENGINEERS.—At a meeting of the Society of Engineers, held on Monday evening, March 4th, in the Society's Hall, Victoria-street, Westminster, a paper was read by Mr. J. Walter Pearse, on "Water Purificaiton, Sanitary and Industrial." In his opening remarks, the author observed that, until the metropolis was furnished with a supply of water from pure sources, private filtration was necessary, and chemical purification was required, as well as mere mechanical filtration. Great diversity of opinion existed as to the value of the various substances used as purifying media, and also as to the form of filter. The first record of a water filter was in 1790, when Johanna Hempel employed porous vessels; and in the following year the ascending principle was first mentioned. Vegetable charcoal as a filtering medium was first named in 1802, animal charcoal in 1818, and solid blocks in 1834. Turning to the modern practice of filtration, the author observed that Atkin's system embodied the last-named principle, finely divided charcoal being agglomerated into porous blocks. The advantage of employing carbon in that form was that the impurities were arrested on the surface, and were easily removed. Major Crease, R.M.A., compressed loose animal charcoal in a granular state, between plates, by means of a screw, the amount of compression being determined by the degree of impurity in the water to be filtered. Major Crease's system is adopted in the Army and Royal Navy. The chief characteristic of Mr. F. H. Danchell's filter was that the ascending principle was used, so that impurities, instead of lodging on the top, fell back on to the bottom of the tank. The Sanitary Engineering and Ventilation Company use mineral carbon as a filtering medium, and cause their cistern filter to be cleansed by the inrush of the supply, and also by reversing the flow. In the Silicated Carbon Filter, mineral charcoal is used as the filtering medium, the main supply filter having three slabs with layers of coarse and fine granular carbon between. In Professor Bischoff's spongy iron filter, the iron exerts a powerful influence on the water, impregnating it with iron, which is afterwards oxidized and arrested, leaving the water pure.

M. Le Tellier's hydrotrimetric purifier was described as removing the hardness from water by throwing down the lime, which was afterwards intercepted by filtration through charcoal. A jet of lime water is made to mingle with the stream from the supply pipe, and the precipitated lime is afterwards arrested by filtration. M. Le Tellier has also invented a high-pressure apparatus on the same principle,

for dealing with large bodies of water used in manufacturing processes, and for purifying the feed water of steam boilers above twenty horse-power. On the same bed-plate are fixed two close vessels, the smaller containing the lime water or other re-agent, and the larger, the mechanical filter for arresting the precipitate, the two vessels being connected by an injector. The supply, which must have a pressure due to a column of at least ten feet in height, enters by an inlet pipe, and most of it passes through the injector into the filtering chambers. A portion, however, descends another pipe, and issues through perforations at its lower end, keeping a disc, which is supported by a spiral spring, in a state of continual trepidation, and thus assisting the combination of the water with the re-agent, previously inserted. The rush of the main supply through the injector draws along with it the lime water from a small pipe, and the two pass together into a vertical tube, which is traversed by pins set alternately at right angles to each other, for bringing about a more intimate union. A valve also admits atmospheric air for aiding in the process. Arrived at the filtering chamber, the lime is thrown down to be removed periodically through a cleaning pipe, and the pure water passes through the filter tubes into the purified water reservoir below, whence it is drawn through a pipe by a pump or injector in connection with the engine and the boiler.

The filter proper consists of wrought iron tubes, perforated with holes, and covered by discs of felt which are compressed between cast iron plates screwed up with a gun-metal nut. The lower ends of the tubes are conical, and fit into sockets screwed into the plates which separate the unfiltered water chamber from the filtered. The number of the tubes varies with the size of the apparatus; but the filtering area of each tube is very large in comparison with the space it occupies, being equal to the height multiplied by its circumference. Each tube may be lifted out of its socket for cleaning or replacing. A cleansing of the whole apparatus is also effected by turning steam into the outlet pipe, which heats the water in the lower chamber and forces it through the tubes and felt, expelling any impurities which may have collected there, to be washed away by rinsing with clean cold water. This apparatus is largely employed by manufacturers on the Continent; and when used for potable water a second filtering medium of vegetable charcoal is added. Mr. A. Durand Claye, director of the laboratory of the Ecole des Ponts et Chaussees, Paris, made some experiments with the Le Tellier filter purifier in 1875, and found that water of 24° of hardness was reduced to 5° after passing through the apparatus, while the solid residue was reduced from 3.31 grammes to 0.92 gramme, a gramme being equal to 15 grains. The reading of the paper was followed by a discussion, after which the following gentlemen were balloted for and duly elected:—viz., as members, Mr. Thomas Andrews, Mr. Christopher George Search, Mr. Francis Brickwell and Mr James Cleminson. As associates, Mr. John Joyce and Mr. Joseph Samuel Beeman.

INSTITUTION OF CIVIL ENGINEERS.—At the meeting on Tuesday, the 26th of February, the paper read was on "Liquid Fuels," by Mr. H. Aydon.

It was stated that apparatus specifically adapted for the combustion of liquid fuels, which comprised every class of fluid hydrocarbons, might be ranged in five classes. The leading principle of their action was either the subdivision of the liquid as spray, or by percolation through a porous bed, or by preliminary conversion into vapor—when the fuel was mixed with air, or with air and steam, by the instrumentality of jets of steam or of compressed air, or it was burned simply as gas in jets.

The results of the use of liquid fuel in Russia and other foreign countries were given in the paper, together with the conclusions of Mr. Isherwood, Chief Engineer of the U.S. Navy, on its employment in steamers.

The author made the general deduction that, although liquid fuel might be burned without the employment of steam, yet it was consumed most economically, and with the best results, in the presence of steam; and, of course, the more highly superheated the steam, the better was the performance.

At the meeting on Tuesday, the 5th of March, Mr. Bateman, president, in the chair, the paper read was "On the Hooghly Floating Bridge," by Mr. Bradford Leslie, M. Inst. C.E. This bridge connected Calcutta on the left with Howrah on the right bank of the Hooghly, at a short distance north of the East Indian Railway terminus.

Of the publications of the Institution we have lately received Doherty on Coffer Dams, used at Dublin, Birkenhead and Hull; also Part 1 of Vol. LI of Abstracts of Foreign Transactions and Periodicals.

IRON AND STEEL NOTES.

FRENCH IRON TRADE STATISTICS.—The official returns of the French iron trade have just been issued, and set forth a number of details which are worthy of notice. On the whole, the industry would seem like our own —to have suffered from depression during the year—but the totals are in several respects very respectable as to size, and, at all events, tend to show that our Gallic neighbors are making considerable progress in this important branch of metallurgy. The total quantity of iron and steel exported from France during the twelve months ending December 31st, 1877, was 169,204 tons only, as compared with 206,248 tons in 1876, or a falling off equivalent to about 17 per cent. The quantity of mineral ore sent out of the country also diminished most materially, for only 79,112 tons were so dealt with in 1877, as against 105,190 tons in 1876. Of this raw material 47,216 tons only went to Belgium against 60,212 tons in the previous year, and 30,104 tons to Germany, as compared with 42,728. On the other hand the mineral ores imported into France reached the total of 975,630 tons as against 849,186 tons in 1876. Of the former aggregate 330,049 tons came from Algeria, 248,226 tons from

Spain, 223,443 tons from Belgium, 139,775 tons from Italy, 30,700 tons from Germany, and 3425 tons only from Great Britain and all other countries. During last year, too, the quantity of cast iron articles imported into France was 212,896 tons, as against 184,344 tons in 1876; of wrought iron, 62,735 tons against 58,385 tons; and of steel, 5009 tons, as compared with 5445 tons in 1876. From the statistics it will be pretty clear that in no sense of the word can France yet be deemed a formidable competitor of our iron manufacturers, for her own exports have not only diminished, but she has also been compelled to use a considerably greater quantity of foreign iron. Her total exports of iron cannot be compared with those of Great Britain, for the whole year's foreign shipments of such articles only amount to about the same as those of this country for a single month. At the same time it would be very unwise to lose sight of the fact that the French are progressing very rapidly in industrial matters, and may presently become "foemen worthy of our steel," or to export their own.—*Engineer.*

RAILWAY NOTES.

THE average locomotive mileage per year in the different countries of the world has been calculated by Prof. Stuermer, of Bromburg, and for the leading countries the figures are given in the *Railroad Gazette* as follows:—France (1873), 23,475 miles; United States (1875), 21,900; Great Britain (1875), 16,865; Germany (1875), 11,834; Austria (1875), 11,700 all Europe (1875) 15,300; East Indies, 13,400. From the same source we learn that the average number of trains per day both ways in 1875 was 20.9 in Europe, 14.7 in the United States, and 8.2 in India.

THE *Lafayette* (*Ind*) *Journal* of December 18th says:—We have often noticed fast time being made on the Wabash Railway, since the putting on of their fast trains, but it was left for No. 4 on last Saturday to beat anything ever done between Lafayette and Toledo. In consequence of the engine breaking down between Danville and Lafayette, the train was over one hour late leaving here, but went into Toledo on time. Engine No. 20—Chapman engineer—took the train to Fort Wayne in two hours and forty-two minutes—the quickest time ever made between Lafayette and Fort Wayne: and from the latter place, engine No. 46—Humphrey, engineer—to Toledo, accomplishing the whole distance of 203 miles in four hours and forty-two minutes. Allowing time for stops, experts claim the distance was run in four hours, which is fully fifty miles per hour. This time has never been equaled in this country by a regular train with no preparation more than usual and making all regular stops.

FOLLOWING is the latest railroad news from Colombia, S. A.: Work on the Antioquia Railway is progressing favorably With 125 men 2900 feet was laid in August. The contractor now proposes to put 500 men on as soon as he can get them. Mr. Ross has a contract for the construction of the "Central Railway" at a cost of $20,000,000. He is to receive a subsidy of $250,000 a year for twenty-two years, and 25 per cent. of the product of the customs. The general direction of the Central Railway will be from a point on the west bank on the Magdalena, below the mouth of the Sogamosa, or in the Cienega de Paturia, and will proceed *via* the Lebrija river to Bucaramanga, and thence through Piedecuesta and Somjil to Bogota, passing as near as possible to the larger towns in the States of Santander, Boyaca and Cundimarca. The contractor will be allowed twelve years to complete the railway, allowance being made for any stoppage of the works for which the contractor is not responsible.

THE annual reports of the condition of railways in Great Britain for 1876 afford some interesting points of comparison with roads of the United States, and the following is made by *Engineering News:*—There are only 16,872 miles of railway in Great Britain, the addition for 1876 having been 214 miles. The number of miles of road in the United States is 77,000—more than four times the number of miles in Great Britain. In the latter country there is one mile of road to every 2,000 persons. In this country there is one mile of road to every 533 persons. The first reflective suggestion by this is that Great Britain is very insufficiently supplied, and the United States very well supplied with railways. But there are other facts in the comparison which show that Great Britain possesses nearly all the railways it needs, while we possess more than can be run at a profit, and therefore, more than we really need. The total nominal capital of the 16,872 miles of British railways, including stocks and loans, is $3,290,000,000, while the total nominal capital of our 77,000 miles is about $4,500,000,000. The capital of British railways represents an average cost of about $190,000 per mile, while that of our railways represents an average cost of about $53,000 per mile. The gross earnings of the British roads for 1876 were $310,000,000, or $18,440 per mile, and the net earnings on our roads were $497,000,000 or about $6600 per mile, and the net earnings $186,000,000 or $2415 per mile. Our 77,000 miles of road earned more than a half more, gross, than the 16,872 miles of British, but the net earnings of the British roads were nearly four times as great to the mile as ours. The percentage of operating expenses in Great Britain is 54 per cent, of the gross earnings; in the United States it is 69 per cent.

ENGINEERING STRUCTURES.

THE HOOGHLY FLOATING BRIDGE.—At a late meeting of the Institution of Civil Engineers, Mr. Bateman, president, in the chair, the paper read was on "The Hooghly Floating Bridge," by Mr. Bradford Leslie, M. Inst. C.E.

This bridge connected Calcutta on the left with Howrah on the right bank of the Hooghly, at a short distance north of the East Indian Railway terminus. Various projects had been

from time to time proposed, but ultimately the preference was given to a floating bridge, as it could be more cheaply and expeditiously constructed than a fixed bridge. The design was prepared in 1868, when it was intended to be carried out by a joint-stock company, but after much delay, in 1872 it was undertaken through the agency of the Local Government of Bengal. The work was commenced in January, 1873, and the bridge was opened for traffic in October, 1874.

The present structure was the first, and, up to this date, the only one of its kind affording headway for river navigation. It divided the port into two sections. The lower part was occupied by sea-going ships and steamers, and the upper part by inland craft and a few coasting vessels. As, however, the graving docks were above bridge, it was necessary that an opening should be provided for the passage of shipping. The extreme rise and fall of the tide during floods was twenty feet, and at certain seasons there was a tidal wave six feet in height. The maximum velocity of the stream was six miles an hour. The depth of the river at the site of the bridge was variable, the greatest depth at low water being six fathoms.

The bridge was 1530 feet long between the abutments, and the roadway was forty-eight feet wide, with footpaths each seven feet in width on both sides, so that the total width of the platform was sixty-two feet. There were four main longitudinal wrought-iron girders at intervals of sixteen feet in the width of the roadway, raised by timber trusses, resting upon pontoons, to a convenient height above the water for accommodating the boat navigation. The platform of the bridge was level for a distance of 384 feet on each side of the center, at a height of twenty-seven feet above the water. Thence it fell by inclines of one in forty to a distance of 584 feet on each side of the center line, where there was a length of twenty feet of level platform twenty-two feet above the water. Between these points and the abutments were the adjusting ways, the shore ends of which were thirty-two feet above low water. The approach on the adjusting ways was by a descent of one in sixteen at extreme low water, and by a corresponding ascent at extreme high water; but at ordinary times it was either level, or only slightly inclined. The platforms of the adjusting ways were supported on the lower flanges of three bow-string girders, the roadway being divided into two by the center girder. The footpaths were carried on cantilevers riveted to the outer girders. The bow-string girders weighed sixty-six tons each. They were 160 feet long between the end pins on which they were hinged, and had the usual trough-shaped upper and lower members. The shore ends of the bow-string girders were suspended on links, which was preferable to carrying them on rollers, even for fixed bridges, as being less likely to get out of adjustment, and tending always to restore the girders to its normal position at its mean temperature. The outer floating ends were hinged to pivot bearings, in order to admit of a slight drift up and down stream.

The floating portion of the bridge was carried on twenty-eight pontoons, coupled together in pairs to secure stability. With the exception of the two pairs in the center, which supported the movable sections of the bridge, each pair carried 100 feet in length of the platform. Each pair was coupled together, at a maximum distance of forty-one feet from center to center, by four timber cills, bolted to the decks of the pontoons at intervals of sixteen feet. These cills constituted the bottom members of the four main longitudinal trusses, the top members being the wrought-iron girders carrying the roadway. With the exception of the upper girders, the whole of these trusses were of teak. The coupled pontoons were further connected by strong horizontal diagonal bracing of bar iron. The timber cills and the bracing being only four feet above the water, the space between the coupled pontoons was not available for navigation, and floating fenders or booms were provided to divert boats from these openings. Ordinarily the main girders overhung the pontoons twenty-one feet, their ends being supported by the inclined struts of the trusses, leaving a width for navigation of forty-two feet, partially obstructed by the raking struts. For the convenience of the country craft, there were two rectangular openings of sixty feet clear span between the fourth and the fifth pairs of pontoons, reckoning from each abutment. The roadway over these openings was carried on eight girders, each $2\frac{3}{4}$ feet deep, and weighing eight tons. They rested on saddles secured to the top of the cross-bearing girders, which were suspended to the ends of the ordinary main truss girders. All the pontoons were 160 feet long, by ten feet beam, with holds varying from eight to eleven feet in depth, according to the dead weight to be carried. Each pontoon, excepting those of the movable sections, was accurately anchored by permanent moorings, laid exactly in line with the center of the pontoon, the distance between the up and the down stream anchors being 900 feet. The strain on the chain cables varied from five to twenty-five tons; their great length afforded the necessary "spring," to allow for the rise and fall of the tide, but a few links were taken in during the dry season, and slacked out again during the flood season.

The 200-feet opening for the passage of ships was one of the most difficult problems in designing the bridge. Owing to the strength and irregular set of the stream and eddies, ships could only be moved at or near slack tide; and it was a rule that all vessels of more than 200 tons must be moved by steam against the tide. The bridge was generally opened twice a week at high water, but occasionally at low water. The opening was effected by removing the two center sections of the bridge bodily. These sections were connected with the fixed portions of the bridge by draw-bridges, which, on being run back, left a clearance of twenty feet on each side of the platform of the movable sections. By means of steel warps, laid to buoys moored for the purpose, these sections were warped up stream far enough to clear the rest of the bridge. They were then disconnected and sheared over, one on each side, leaving a fair way clear of all obstructions.

The bridge was closed by reversing these proceedings. The ordinary time taken in opening the bridge was fifteen minutes, and in closing it twenty minutes.

There was a daily traffic of about 6000 tons of heavy goods, which were conveyed in bullock carts, besides foot and carriage passengers. The iron work of the pontoons weighed 1650 tons, that of the girders 875 tons. The whole of this, as well as the mooring chains, was sent from England, and was erected and riveted up in Calcutta. The teak timber, which weighed 1500 tons, was procured from Burmah.

The different parts of the structure were minutely described. An account was also given of the operations connected with the laying of the forty-eight permanent moorings, with the fitting of the truss-work, with the hoisting into position of the sixteen sixty-feet girders, and with the erection and launching of the 160-feet bow-string girders. The particulars were likewise recorded of an accident that delayed the completion of the work about three months. This arose from a deeply-laden ship fouling two vessels, which parted from their moorings, and both were sent up stream on the top of the "bore" at the rate of five knots on hour. One vessel went through the center opening, but the other struck the bridge, causing three pontoons to be sunk, and the superstructure to be completely wrecked.

A Monster Mine Engine.—A piece of machinery that has given employment for several months to about 500 skilled artisans, has been completed at the Union Ironworks, at a cost of $300,000. This great expenditure of labor and money has embodiment in the largest engine ever constructed on this coast. Technically described, the engine is a horizontal, low-pressure, compound, condensing, of 1500 horse-power. With boilers, pumps and gear it aggregates a weight of 1200 tons. One of the cylinders is so heavy that a special car will have to be constructed to transport it to its destination—the Yellow Jacket Mine—where a shaft is being sunk to a depth of about 2300 feet to strike the Comstock. The engine is to be used at this shaft for pumping. It is now being put together at the foundry preparatory to shipment. This engine rests on a horizontal base, 64 feet in length, each side of which is cast in three pieces for convenience of shipment. The breadth of the engine is 18 feet. The power is communicated from the two cylinders to a forged cross-head, to which is attached the shaft connecting with the y bob working the pumps. The cross-head is the largest piece of iron ever forged in San Francisco. It weighs 22,000 pounds, is 21 feet in length, 9 inches in thickness one way and 3 feet the other. The shaft and crank weigh 26 tons. On each side of the engine, about half way between the cross-head and the connection of the shaft with the y bob, is a flywheel 30 feet in diameter and weighing 30 tons. These flywheels are connected by a shaft 18 inches in diameter, running through the main shaft. The cylinders consist of an initial cylinder 32 inches in diameter, weighing 12 tons, and an expansion cylinder 65 inches in diameter, weighing 30 tons. The pistons of these cylinders have a 12-foot stroke. They carry steam pressure of 130 pounds, expanded eightfold. The cylinders and cylinder heads are steam-jacketed, being covered with a thick coating of asbestos, a non-conductor of heat. The engine is supplied with an air-pump of the most improved construction, fitted with an automatic injection-valve, and is operated with O'Neil's cut-off valve motion. Every modern mechanical appliance has been embodied in this engine, and every part which will be subjected to wear has been case hardened. During the progress of the work several costly machines were constructed which were necessary to make parts of the engine. The proprietors of the works, Messrs. Prescott, Scott & Co., have taken more than ordinary pride in the execution of the contract, refraining in every particular from incorporating in the machinery any part not strictly of San Francisco. This has been done in the interest of home industry, which had some weight with the Bonanza firm when they awarded the contract, this firm being the principal holder of Yellow Jacket stock This firm is demonstrating the feasibility of manufacuring all classes of engines in this city, and they entertain the opinion that it will not be many years before the importation of engines and pumps from the East will be done away with altogether.

There are two massive bronze plates fixed on each side of the base castings of the engine. One of these is emblematic of the industry to which the machinery is devoted. In the center is the figure of a miner at work in the drift, and surrounding it are surface scenes on the Comstock. The other plate bears the following inscriptions:—Yellow Jacket Mining Company, T. G. Taylor, superintendent; William H. Patton, construction engineer; Prescott, Scott & Co , builders 1878." The letter "S" in the left-hand lower corner, and the letter "F" in the right-hand lower corner.

The new shaft of the Yellow Jacket Company, in which the machinery is to be placed is estimated to cost $1,000,200. This figure covers the cost of the machinery. The shaft is now down about 1600 feet, and to push the work to completion it will be raised from the 2200-foot level. The 2200-foot level is represented to be only 40 feet from the line of the shaft. When the connection is completed, all the drainage of the mine will be carried through it. The machinery has sufficient capacity to carry the working to a depth of 3000 feet.—*San Francisco Mining and Scientific Press.*

ORDNANCE AND NAVAL.

A New Twin Steamer.—The trial trip of the new twin steamer *Express* which has been built by Messrs. A. Leslie & Co., shipbuilders, Hebburn-on-Tyne, for the Channel Passage Company, for service between Dover and Calais took place recently. The passage between Dover and Calais is a very turbulent, and therefore an uncomfortable one for passengers; and the question how to make the voyage lighter and steadier, so as to remove the

discomfort attending it, has often presented itself to nautical minds. Some few years ago Captain Dicey, the originator of the Channel Company, designed the *Castalia* for this object and, so far as equability and comfort were concerned, she thoroughly answered her purpose; but her speed was so far below that of ordinary steamers and, therefore, although many preferred the more pleasant passage and chose to take the slower vessel, the majority elected rather to face the storm and have the advantages of the swifter mode of transit. Mr. Leslie, however, undertook to produce a vessel having the qualities required, and the result has been the *Express*. She is a sister ship to the *Castalia*. The *Castalia* has something like 1100 horse-power. When it was made patent that that vessel had not enough engine power to enable her to compete successfully with the Dover and Calais mail boats, Mr. Leslie and Mr. Parkes experimented on the Thames with two Woolwich paddle boats locked together, and from these experiments, combined with the *data* gathered from the trials of the *Castalia* they established the base for calculations for building a new boat to attain double her speed. The difficulty in the way of designing a new ship of the dimensions of the *Castalia* with the same draught of water, 7 feet, but with a propelling power of 4000 horses as compared with 1100 horse-power, was considerable. The extra displacement, however, was obtained by forming the inside lines of the two ships elliptical, and making the rudder form a part of the body of the ship. The *Express* was guaranteed to have a draught of no more than 7 feet, and to be capable of working at a minimum speed of 14 knots—the difficulty of this being to get sufficient power into her without immersing her too much in the water, and this Mr. Leslie has accomplished. The draught of the *Express* is about 1 foot less than the *Castalia*, her length 10 feet greater, and she is 1 foot broader. The two hulls are each about 1 foot wider, and the channel between the two ships is slightly narrower in the *Express* than in the *Castalia*; the great difference in construction between the two vessels, so far as the hulls are concerned, however, is, that whereas the *Castalia* is, as it were, two half ships placed a certain distance apart, forming between them a channel, the sides of which are parallel the *Express* is two complete symmetrical ships, thus making the channel wider towards the ends of the vessel, and narrower towards the paddle wheels. This has the result of giving a more plentiful supply of water to the wheels, and enables them to utilize a much greater proportion of power than with the parallel channel. In the *Express* the two hulls are very rigidly united together by four transverse iron girder bulkheads spanning across the channel. The rudders, of which there are four, one at each end of each ship, act also as bows without any resistance. The veesel is steered by steam, the steering gear being supplied by Messrs. Brotherhood & Hardingham, London. The whole of the passenger accommodation is provided on the superstructure. The saloons are all approached by circular staircases from the upper decks; a large general saloon and a ladies' saloon are forward and the refreshment saloon and range of state rooms for private families aft. The furnishing is all of the highest order. The vessel accommodates 1000 passengers. The engines which have been suplied by Messrs. Black, Hawshore & Co., Gateshead, are 4000 indicated horse power. They are diagonal inclined engines, having two cylinders in each ship working on one crank pin. The clyinders are 63 inches in diameter, with 6 feet stroke and 40 revolutions per minute. There are two patent leather paddle wheels working independently of each other. The trial trip on Saturday extended along the coast to Coquet Island, a distance from the Tyne of 22½ miles The vessel sailed remarkably steady, and a very pleasant day was spent by the Company on board. The runs from Coquet Island back to the Tyne were made a test and the distance was done in one hour and twenty-two minutes, an average of 14.48 knots per hour. The distance from the Tyne to Coquet is one mile and a half longer than from Dover to Calais. The trial was considered highly satisfactory. The *Express* is expected to commence the Channel service next month, but at all events will start in time for the Paris Exhibition.

BREECH-LOADING ARTILLERY.—Mr. Krupp, the inventor of the celebrated German siege gun, has been induced, by the discussion which took place in the House of Commons, on the 12th of March, relative to the comparative merits of muzzle and breech-loading artillery, to indite a letter setting forth his views, which appeared in *The Times*. Having premised that the statements made by Lord E. Cecil might lead to an erroneous impression, if allowed to pass unanswered, the writer says that England alone of European nations remains the champion of the muzzle-loader, and then argues that the failure of the English breech-loader is not proof that the principle is not good, or that the system is not susceptible of improvement. As to the German guns said to have become unserviceable during the Franco-German war, he says: "I have authentic information in reference to these guns, and all of them were, indeed, serviceable during the whole of the war, and only required some slight repairs afterwards, with the exception of four or five guns. The guns in question were a part of a number supplied to Prussia, and were constructed with copper expanding ring in the square double edge. They suffered from the escape of gas, caused principally by the double wedge slightly giving way, but none of them burst. The Saxon artillery had the steel centring ring in bore of gun and solid single wedge, and not one of these guns failed. The experience then gained has led to the perfection of the gun in detail, so that, after the conclusion of the war, the German Government remodeled the whole of its field and siege breech-loading artillery. It is also stated that the bursting of my gun on trial is not infrequent. Since the commencement of manufacturing steel ordnance in 1847 to the present date, I have supplied upwards of 17,000 guns of all

calibres, and of these only eighteen have failed, or averaging one gun in 948. By far the larger part of these eighteen failures occurred through the breaking away of the breech, owing to its then rectangular form, a form that has since been altered to the semi-circular, and not a single mishap has occurred since at this part of the gun." Alluding to the statement made that the Krupp guns used by the Turks in the recent war had to be sponged out with soap and water after each round, he contends that the fouling was due not to the build of the cannon, but to the quality of the powder, and in support of his position asserts, that with guns made by him recently fifty rounds and upwards can be fired without sponging. He then denies that the rate of firing with his gun is only one round in five minutes, and claims that at recent experiments conducted by Belgian officers the average rate was twenty five rounds in twelve minutes, with the gun laid and sighted at each round. Mr. Krupp's belief in the superiority of his gun over the English, he claims, is based on experience. When speaking on this head, he says: "Recently (August 21st, 1877) my views of the superiority of my gun over the English system have been confirmed by trials between a 17 cm. (6⅔ inch) gun of my construction, made in Holland, against an English 9-inch muzzle-loading gun, and notwithstanding the great difference in size of the guns my 17 cm. gun proved itself of greater power in piercing armor plates than its larger opponent upon the muzzle-loading system, and also in other characteristics that give value to a gun, such as accuracy of aim, &c. The guns were fired with the same class of powder and at the same shield." The letter also contains an explanation of the statement that a proposition was made to the English Government by Mr. Krupp to lend one of his guns for £15,000, upon condition that, if it should be adopted, an order for £2,000,000 of guns should be given him. In brief, he thinks that his requirements are warranted by the costly experiments, &c., he has had to conduct, without aid from any Government. The letter terminates with this business-like sentence: "I have expressed to the English Government, and again express to it, that I have every desire to place my system at their disposal, and to enter into competitive trials; but they must be on such terms that my interests shall have equal consideration with those of the English Government."

BOOK NOTICES.

GENERAL REPORT ON THE PROVINCE OF KORDOFAN. By Major H. G. PROUT. Cairo: War Office.

In December, 1874, an expedition of reconnoissance left Cairo under the command of Colonel Colston of the Egyptian General Staff, with orders to ascend the Nile in boats as far as Wady Halfa, and then proceed, by land along the left bank of the Nile, to Debbé, whence reconnoissance was to be made, first, of Wady Massoul (or Matoul), and, afterwards, of one of the routes from Debbé to El-Obeiyard.

Colonel Colston had under his orders, Lieut. Colonel Reed, of the General Staff, as second in command, five junior Officers of the Staff, a naturalist (Dr. Pfund), an Army Surgeon, a squad of Staff-Soldiers, a section of Artillery and a platoon of Infantry.

The expedition was expected to arrive at El-Obeiyard, capital of Kordofan, at least one month before the commencement of the rainy season of 1875, and, after a short rest there; was to proceed to Darfour, and there co-operate with the Staff exhibition under Colonel Purdy for the rapid reconnoissance of that country and for subsequent explorations further south in Central Africa.

Before the arrival of the party at Dongola, Colonel Colston became satisfied that his second in command, Lieut. Colonel Reed, would not be able to bear the fatigues of such an expedition, and he therefore ordered that officer to return to Cairo, and applied to the Chief of the General Staff for another field officer.

On the 2nd of February 1875, Major Prout, who was then serving as Chief of the 3rd Section of the General Staff Bureau, in the War Office at Cairo, was designated as successor to Lieut. Colonel Reed; and was ordered to proceed, by the way of Suez, Suakin, Berber and Khartoon, to join Colonel Colston.

The orders, letters, reports, maps and telegrams which appear in the appendix set fourth clearly the route followed by Major Prout, the valuable work preformed by him during the journey, the circumstances under which he joined Colonel Colston, and those under which the responsibilities of the command of the expedition feil upon him.

The report on Kordofan itself, with the map of the Province and the conscientious appendices, the route-maps and special reports, evidence how much can be done by an able, instructed and honest-minded officer, in those regions, in one year, when that officer thinks less of the risks and discomforts around him, than of the accomplishment of duty for duty's sake.

The account is briefly but pleasantly given and is a valuable addition to our knowledge of this region. The maps are good and the sketches are sufficient for the purpose designed.

ETUDE SUR LES MACHINES COMPOUND. Par A. DE FREMINVILLE. Paris: Arthur Bertrand. For sale by D. Van Nostrand. Price $1.80.

This is a prize essay on Compound Engines, prepared for the French Academy of Sciences.

The subject is treated analytically and exhaustively.

The illustrations are expansion curves only, to the number of twenty.

The book is a quarto pamphlet of fifty-nine pages.

TRAITE D'ASTRONOMIE ET DE METEOROLOGIE APPLIQUEES A LA NAVIGATION. Par G. CHABIRAND ET L. BRAULT. Paris: Bertrand. Second Volume. For sale by D. Van Nostrand. Price $4.00.

This voluminous treatise contains all that the ordinary student of navigation needs to know, and something more. The demonstra-

tions are expanded so as to be perfectly clear to the student of ordinary mathematical capacity, who, from necessity, works without aid from an instructor. This is the acknowledged merit of French scientific works. Everything relating to navigation is treated with equal fullness.

ROCK BLASTING. By GEO. G. ANDRE, F.G.S. London. 1878. For sale by D. Van Nostrand. Price $4 25.

The use of new explosives in blasting rocks, and the widely extending use of the machine drill for boring, called for many changes in the labor methods adopted in quarrying, tunneling, etc.

The present treatise is a well printed and well illustrated volume of 200 pages, containing chapters on: Tools and Machines for Rock-Blasting; Explosive Agents; Principles of Rock-Blasting; The Operations as pursued in Quarries and Tunnels; Blasting under Water.

The Author is well known by his previous works, Coal Mining and Mining Machinery.

A TREATISE ON CHEMISTRY. By H. E. ROSCOE, F.R.S. and C. SCHOOLHEIMER, F.R.S. Vol. I. For sale by D. Van Nostrand. Price $5.00.

This fine octavo of 760 pages is devoted exclusively to the Chemistry of the non-metallic elements. When we consider the eminence of the authors, the space devoted to this portion alone of the entire subject, and the fact that it is only just completed, we feel justified in asserting, that no other work can compare with it in accuracy or completeness. It may be necessary to add, that no space is devoted to chemical technology, and only just enough to chemical philosophy; it is simply a complete treatise on general chemistry that any student may read with satisfaction.

REMUNERATIVE RAILWAYS FOR NEW COUNTRIES. By RICHARD C. RAPIER. London. 1878. For sale by D. Van Nostrand. Price $6.00.

This book professing to aid in making estimates for railways in new countries, is but little more than an overgrown, illustrated catalogue with gilt edges.

A very little information is spread over a large amount of paper. For example: to represent six different cross sections of railway rails with their fish plates, six quarto pages are employed, and as most of the machinery represented is on a similar scale, we conclude that the main object of the author is to advertise the wares of Ransome & Rapier, whose names are conspicuous in many places throughout the volume.

TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS. Vol. V. Easton: Published by the Institute.

This new volume includes the Proceedings of Meetings from May 1876 to February 1877, and a general index of all the published volumes. The value of these papers to the mining engineers everywhere is sufficiently attested by the fact that most of the papers have been republished in the scientific journals of Europe.

Notwithstanding the fact that mining interests have suffered in the general depression of business, the transactions of the Institute are in no sense less interesting or important than in former years.

The present issue contains 630 pages exclusive of the general index and eleven folding plates.

MISCELLANEOUS.

THE total power of all the steam engines existing in France according to recent official statistics, is 1,500,000 horse-power, representing the actual labor of 4,500,000 horses, or 31,590,000 men. This last aggregate is equal to ten times the present industrial population, which amounts to 8,400,000 souls, but from which must be subtracted old people, women, and children, leaving a remainder of 3,200,000 working men. *La Nature* compares the above data with the similar statistics of 1788, before steam engines were introduced in France, and illustrates the revolution which steam and improved machinery have produced. Ninety years ago, in every £40,000,000 worth of French products, 60 per cent. of the value represented labor and 40 per cent. raw material. To-day this ratio is exactly reversed, although labor has increased 40 per cent. At the present time the total industrial productions of France aggregates a value of about £480,000 000. Of this £280,000,000 represents raw material and the remainder labor. If the same proportion as existed in 1788 applied now taking into account the increase in labor noted above, less than eleven-twelfths of the above amount, or £440,000,000 would be the cost of handiwork. Roughly, then, steam engines and improved tools have produced an economy of £240,000,000; but, more than this, if they were suddenly swept out of existence and forgotten, there are not enough men and animals in the country to supply an equivalent amount of power, and even if there were there would be no way of procuring the necessary food for their support.

ON the 11th inst. Captain F. J. Evans, Hydrographer to the Admiralty, read a paper before the Geographical Society "On the Distribution of the Earth's Magnetic Force at the Present Time." The paper gave a historical sketch of the invention and improvements of the mariner's compass, and noted the discoveries which that instrument had made of the action of the magnetic forces in different parts of the earth. The lecturer connected the phenomena thus brought to light with the variations of the compass, a due regard to which was absolutely necessary for safe navigation. In one region of the globe—the smaller—this variation was westerly, and in the other—the larger—it was easterly. Westerly a variation prevailed in the Atlantic and Indian Oceans, and easterly in the Pacific Ocean. As a matter of fact the magnetic condition of the globe was always varying, but in what manner and to what end was absolutely unknown. Auroras and earth currents were then discussed, and notice was taken of the magnetic discoveries made during the voyage

of the Challenger. Having marshalled the various facts and hypotheses concerning magnetic phenomena, the lecturer in conclusion said, "Such are the facts, and how are we to interperet them? Whichever way we look at the subject of the earth's magnetism and its secular changes, we find marvelous complexity and mystery; lapse of time and increase of knowledge appears to have thrown us farther and farther back in the solution. The terrella of Halley, the revolving poles of Hansteen, and the more recent hypothesis of the ablest men of the day, all fail to solve the mystery."

M. du Moncel has recently communicated to the French Academy of Sciences a paper "On the Relation between the Diameter of Cores of Electro-Magnets and their Length," the conclusions reached in which are as follows: (1) The dimensions to be given to an electro-magnet should essentially depend upon the electric force which is to effect it, and upon the resistance of the circuit on which it is interposed. When the circuit is long and the electric source weak, the cores should be long and of small diameter; when, on the contrary, the circuit is short and the electric force in tense, the core should be of large diameters. (2) For equal circuit resistances, the diameters of an electro-magnet established under maximum conditions should be proportional to the electro-motive forces. (3) For equal electro-motive forces, these diameters should be inversely as the square root of the resistance of the circuit, the resistance of the battery being included. (4) For equal diameters the electro-motive forces should be proportional to the square roots of the resistances of the circuits. (5) For a given electro-motive force and with electro-magnets placed in their maximum conditions the electro-motive forces of the batteries which excite them should be proportional to the square root of the resistances of the circuit.

The Trade in Boxwood.—It appears that, in consequence of the continued increased cost of boxwood and its rapid decrease in quality, one of the principal importers of this and other hard woods into this country has succeeded in introducing two American woods to be used instead of box in the manufacture of shuttles, a purpose for which immense quantities of boxwood have hitherto been used. The woods so substituted are those of the cornel and persimmon. The first is apparently the *cornus florida*, a deciduous tree, about 30 feet high, growing abundantly in woods in various parts of North America. The wood, though of small size, is hard, heavy, and close grained, and is used chiefly in America for the handles of tools and for shuttle-making, and, when properly seasoned is much superior to Persian boxwood. The same may be said of the persimmon (*diospyros virginiana*), a tree belonging to the ebony family, a native of the United States, where it grows to a height of from 50 feet to 60 feet, and a diameter of a foot or 18 inches. The heartwood is of a dark brown color and very hard. The trunk is covered with a very thick, hard, and rugged bark. One great point to be particularly remembered in the preparation of these woods for shuttle making is the very gradual drying by artificial means; this is more particularly recommended in the case of the cornel, undue haste in seasoning, it is said, having in some cases created a prejudice against the wood. As an illustration to some extent of the effects of the war, it may be stated that while in 1876 over 10,000 tons of boxwood were imported, the year just past shows a return of only between 4000 and 5000 tons. A large proportion of this wood is the produce of the forests on the Caspian Sea. Though the supply from the Black Sea provinces has for some years past been decreasing, it is well-known that untouched forests of the wood exist in Russian territory, and it is hoped and expected that at the close of the present disastrous war these forests may be opened up so that we may get abundant supplies of good wood for some time to come.—*Society of Arts Journal.*

Influence of Trees on Rainfall.—There can be little doubt that there is a distinct connection between the rainfall and mean temperature of a country and the number of trees the latter may possess. Trees are magnificent regulators of climature. They are to it what the pair of revolving "governor-balls" are to a stationary engine. When the engine is going too fast, the "governor-balls" distend, and "throttle" or compress the aperture whence the motive steam-power is issuing. When the engine is working slowly, the balls droop, and so open the valve as to allow more steam to issue. The same with the woods and forests of a country. When the rainy seasons are on, every tree and plant absorbs some of the moisture, and stores it away in its own tissues. It thus prevents great quantities from flowing off the surface, and gathering into rills and rivulets, and so swelling the main rivers as to cause them to overflow their lowest lying banks. During periods of drought the leaves of the same forest give out the moisture they consumed into the atmosphere, and so prevent its being as dry and parching as it otherwise would have been. During the hours of night, also, the surfaces of the leaves become colder than the air, and thus the moisture contained in the latter is condensed upon them as dews. In many parts of Arabia this is the only kind of waterfall with which the parched earth is visited. The destruction of woods and forests, therefore, is always attended by an alteration of climate for the worse. It becomes more irregular. There are now alternate periods of rainfall and consequent floods, and of droughts. No country in the world has been so altered in this respect as the United States, for in no other has there been so much clearing of forest land within the last two centuries. In Italy great destruction of forests has taken place, and the summers are now more arid and hot in consequence. The reader will find in the Hon. G. Marsh's "Physical Geography as influenced by Human Action," a long list of parallel cases, where men have unconsciously modified the climate of the country in which they dwelt.—"*Watery Wastes*," *by Dr. Taylor, F.G.S., &c.*